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This issue of Exploratorium Magazine focuses on microbes. Different types of microorganisms are introduced based on their living environments or whether they are harmful or beneficial. Contents include: (1) "It's a Small World" (Blake Edgar); (2) "The Human Body: A Complex Ecosystem" (Nik Walter); (3) "The Hills That Bacteria Built" (Robert Evans); (4) "Try This!Ñ-Flavorful Fermentation: Kimchee" (Karen E. Kalumuck); (5) "Germ Warfare on the Home Front" (Ellen Klager); (6) "Fragments" (Carolyn Strange); (7) "Sex and the Single Microbe" (Eric Engles); (8) "Getting Miçrobes to Do Our Dirty Work" (Carol Blaney); (9) "Try This!Ñ-Bacterial Terrarium" (Fred Stein); (10) "The Domestic Yeast" (Alice Cascorbi); and (11) "Ask Us" (Mary K. Miller). (YDS)

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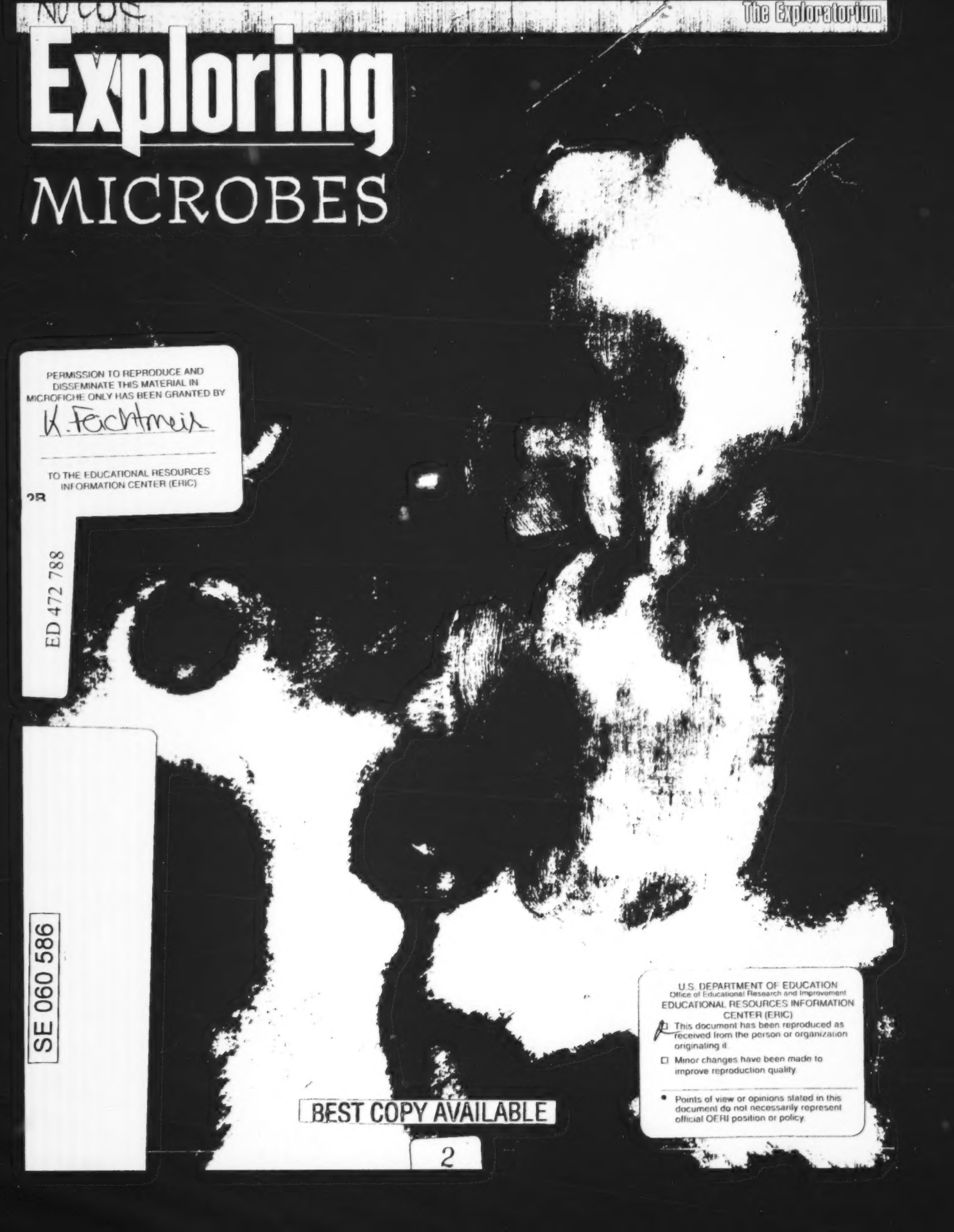
Exploring MICROBES



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Earth Region. A monoprint by John Alexander

EXPLORING

Vol. 21, No. 2, Summer 1997

Exploring is a magazine of science, art, and human perception, produced by the Exploratorium. *Exploring* communicates ideas that museum exhibits can't easily demonstrate, extending the museum beyond its physical walls. Each issue concentrates on a single topic, examining it from a variety of viewpoints. This focus allows us to investigate and discuss interconnections between apparently unrelated phenomena, revealing the essential unity of nature.

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From the Director

Dear Friends,

At the Exploratorium, you can experience nature and science in new and exciting ways—by watching a tornado form, seeing the beating heart of an unborn chick embryo, or controlling the patterns created by a desert windstorm.

This summer, we will take you beyond the extraordinary in our newest exhibition, *Hidden Kingdoms: The World of Microbes*. In it, you will journey into the lives of creatures that have always been around you, but that you have probably never seen. Using E-Z View microscopes, you will see protozoa, bacteria, and other tiny creatures that live in a drop of water—or on a strand of your own hair.

Models of microbes 1000 times their normal size will give you a feeling for what it would be like to be one of the smallest creatures on earth. Through videos, interactive computers, and other exhibits, you will discover some old enemies, like the rhinovirus that causes the common cold. You'll also be introduced to some friends you didn't know you had—like the mold used to create the antibiotic penicillin, and the tiny bacteria that break the food you eat into nutrients your body can use, or other bacteria that transform kitchen garbage into garden compost.

Until the invention of the microscope, no one had ever seen these tiny beings—or even knew that they existed. You'll be amazed by the diversity of size, scale, color, and shape that exist in the microbial world. Each weekend throughout the summer, we offer special events and demonstrations that will introduce you to the yeasts that turn water and flour into bread, or turn water and grain into beer. You'll see films that take you into the life of a dust mite, or show you tiny creatures that survive the most extreme environments—from the Arctic ice to the boiling hot springs of Yellowstone National Park.

I hope that you will come and visit us at the Exploratorium this summer, and let us introduce you to the amazing world beneath the surface of our everyday lives. I promise you an extraordinary journey, one that you will never forget.

Yours,

Goéry Delacôte
Executive Director

Hidden Kingdoms: The World of Microbes will be at the Exploratorium from June 1 through September 7, 1997.

BE CAREFUL! The experiments in this publication were designed with safety and success in mind. But even the simplest activity or the most common materials can be harmful when mishandled or misused. Use common sense whenever you're exploring or experimenting.

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MICROBES

4

The Human Body: A Complex Ecosystem
by Nik Walter
Each of us is simultaneously a supermarket, playground, and honeymoon suite for bacteria and other microbes.

8

The Hills That Bacteria Built
by Robert Evans
Travel with us to the Texas/New Mexico border and discover how bacteria built limestone hills.

11

Try This!
Flavorful Fermentation: Kimchee
by Karen E. Kalumuck
Ferment to your heart's content—learn to make kimchee.

12

Germ Warfare on the Home Front
by Ellen Klages
America is now squeaky clean, at least in terms of germs. But it wasn't always so. Learn the history of our germ-fighting efforts from the 1850s onward.

16

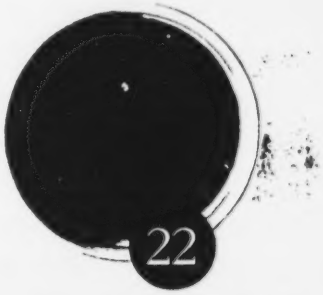
Sex and the Single Microbe
by Eric Engles
Visit the world of microbial mating.

18

Getting Microbes to Do Our Dirty Work
by Carol Blaney
Microbes have gotten a bad rap, but some have a marvelous, unappreciated side.

21

Try This!
Bacterial Terrarium
by Fred Stein
Grow your own colonies of multicolored microbes.



22

The Domestic Yeast
by Alice Cascorbi
From beer to bread to our own bodies, yeasts are everywhere.

Departments

2
First Word
It's a Small World

15
Fragments
Typhoid Mary, and more

26
Ask Us
Answers to readers' questions

27
Reviews & Resources
Tools and Toys
Related Reading
Credits and Acknowledgments

First Word

by Blake Edgar

IT'S A SMALL WORLD

There's the home message: microbe rule

We like to think that we're pretty special, now that there are nearly six billion of us occupying the planet. But microbes, or microorganisms, are literally everywhere, in untold billions. Named from the Greek words for "small" and "life," microbes include any organism visible only under a microscope, such as yeasts, amoebas, and bacteria. Just considering bacteria alone, microbes live on us, in us, and in any habitat you can think of, even deep underwater and deep underground. It's quite possible that wherever microbes are able to survive, they do. Metal-eating microbes are slowly ingesting the orbiting *Mir* space station, while others may even be aboard asteroids and meteors hurtling to destinations unknown.

Whether or not microbes have ever inhabited Mars or any other planet, we know that without bacteria being around for the past few billion years, no other life could exist on earth. Chemical traces of the fossils of primitive bacteria, some of the earth's earliest life, have been detected in 3.8-billion-year-old rocks. Actual fossilized bacterial bodies have been found in rocks that are 3.5 billion years old. Soon after the earth congealed and cooled enough to host life, it seems, bacteria began to evolve. Among these early forms were blue-green chains of cyanobacteria.

which developed the novel skill of deriving energy from sunlight and extracting hydrogen from water to build their cells and fuel themselves. They drew carbon from the atmosphere and expelled massive amounts of oxygen, and this dawn of photosynthesis created a chemical environment suitable for all subsequent life on the surface.

So we owe a huge debt to bacteria, and we should remember the role they play as sustainers of life when we're quick to dwell on harmful bacteria, those responsible for cholera, salmonella, bubonic plague, and other ills. Bacteria and other microbes clean our air and water, nourish soil and plant roots with nitrogen, and scavenge the dead and decaying to release nutrients for the living. All of us inadvertently repay our debt in part to those bacteria that find shelter and a free meal inside us.

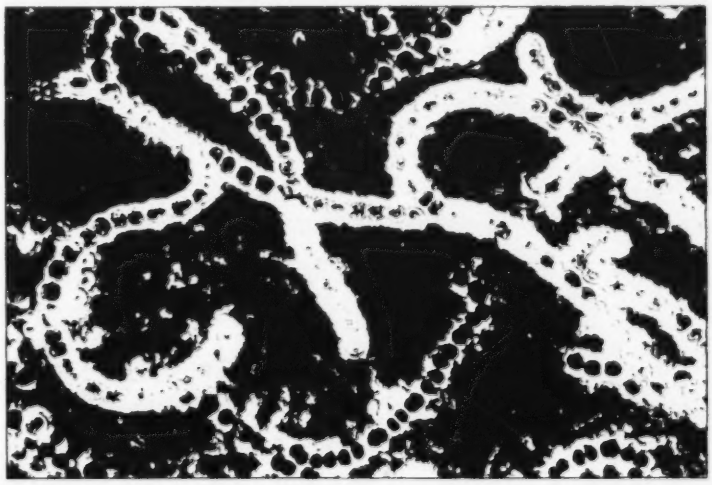
Bacteria also deserve our wonder and respect for being by far the most numerous living things on earth. Recent discoveries show that bacteria are much more diverse, widespread, and hardier than we could have imagined. Less than 1 percent of microbes occurring in nature can be cultured and observed in a laboratory, so we are only barely beginning to skim the surface of microbial diversity. Yet everywhere microbiologists look, they turn up new and astounding forms, leading many to suspect that microbes make up the vast majority of life's genetic diversity, and the bulk of its biomass.

For example, seawater collected from the California coast and other parts of the Pacific, both shallow and deep, contained abundant genetic bits from previously unknown types of bacteria that may have been evolving in the open ocean for at least the past billion years. The closest known relatives of these cool-water forms are heat-seeking members of an ancient group of microbes called Archaea, which are perhaps the closest living relatives to whatever first populated the planet.

The Archaea capturing the most attention lately include the so-called "extremophiles" that flourish in the earth's harshest habitats, from terrestrial geysers and Antarctic ice to seafloor volcanoes. They thrive in extremes of heat or cold, span pH ranges from acidic to basic, and endure what to us would be crushing pressures and desiccating densities of salt. Many extremophiles have come under economic scrutiny as a source of potential industrial enzymes and other chemical products.

One recently discovered member of this august subgroup of Archaea, *Pyrolobus fararii*, holds the current record for survival at the hottest temperature life is known to endure. The lobe-shaped microbe lives 3,650 meters deep on black smokers, chimney-like volcanic vents on the mid-Atlantic Ridge, where water temperatures hover between 90°C and 113°C (about 212°F). It can't even grow if the water drops to under 80°C.

Opposite page: **The *Mir* space station orbits the earth.**
Below: **A common filamentous cyanobacteria that's useful in enriching soil by fixing nitrogen.**



Just last year, geneticists from The Institute for Genomic Research mapped the complete genome of another kind of heat-loving Archaea, *Methanococcus jannaschii*, which was collected from a hydrothermal vent off the west coast of Mexico. This minute microbe, a millionth of a meter long, contains 1,738 genes, and more than half of them had never been seen before in any other organism.

The same scientific team has also sequenced the genes of the smallest known free-living organism, the bacterium *Mycoplasma genitalium*. It possesses only 470 genes, and yet a quarter of them were new to science. This parasite of the urinary tract of people, who contain somewhere between 60,000 and 100,000 genes, must be verging on the minimal number of genes needed to support and replicate a living thing.

What about the biggest bacterium? That claim currently goes to *Epulopiscium fisbelsoni*, which lives inside the guts of tropical surgeonfish. This microscopic giant can exceed 80 × 600 micrometers in size and has a million times more volume than a typical bacterium, such as our gut-dwelling *Escherichia coli*.

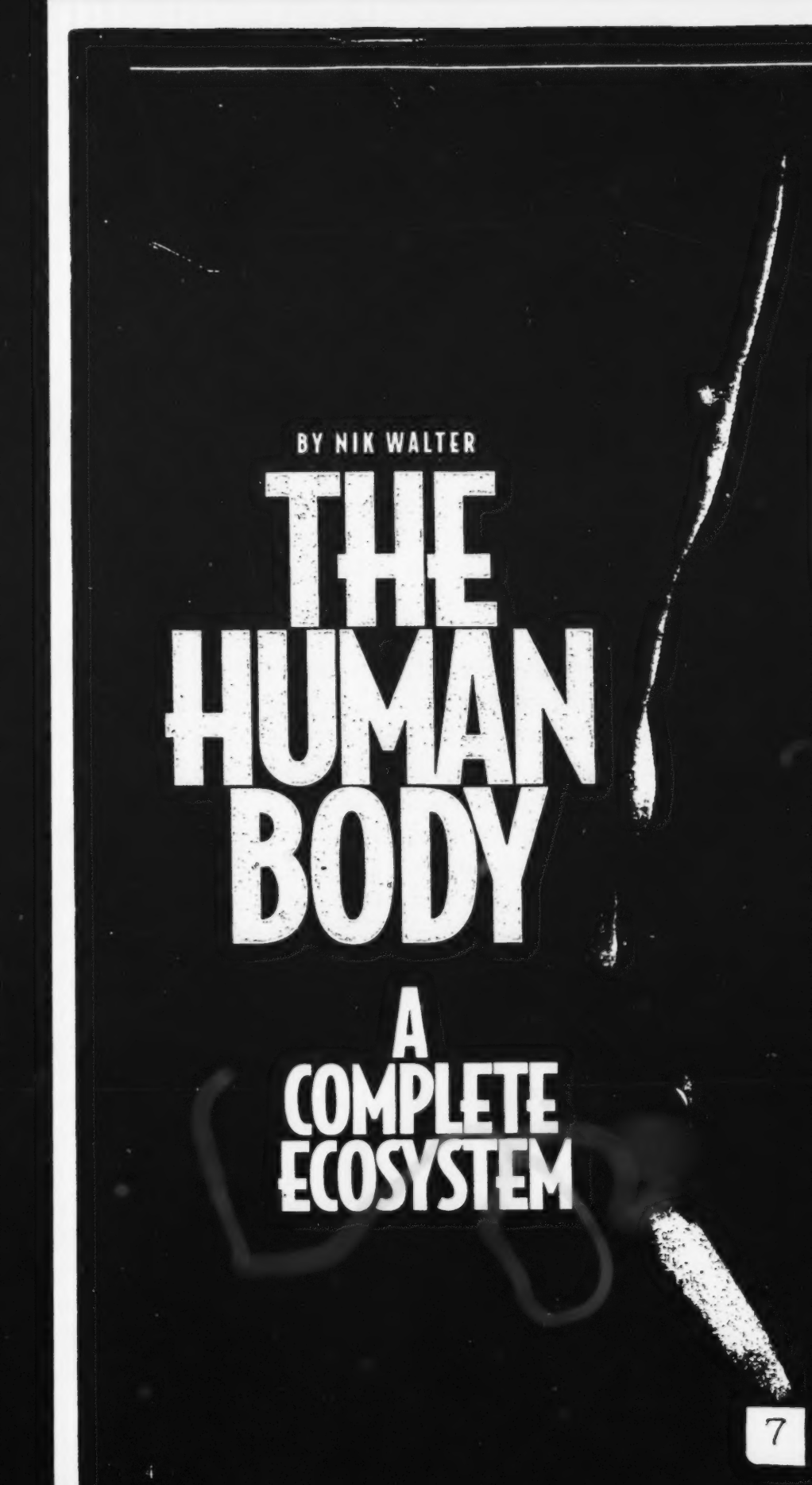
For a final microbial marvel, consider *Deinococcus radiodurans*, a bacterium discovered because it was the only thing left living on irradiated fruit. It survives a DNA-shattering dose of 1.5 million rads of radiation (more than 3,000 times the lethal amount for us). Within a few hours, *Deinococcus* literally pulls itself back together and reassembles its genetic pieces.

Bacteria have been on earth almost 1,000 times longer than our earliest hominid ancestors. They can evolve rapidly to changes in their surroundings and seemingly reside anywhere. No doubt they'll endure, because old bacteria never die, they just keep dividing. Welcome to the planet of the microbes. ■

BY NIK WALTER

THE HUMAN BODY

A COMPLETE ECOSYSTEM



Most of us picture an ecosystem as an undisturbed environment, such as a secluded pond or a pristine mountain range, where various species of plants and animals live together in a stable balance. It needs a little more imagination to visualize a thriving ecosystem under the pavement of a six-lane freeway, although the soil beneath the incessantly moving traffic may be teeming with vermin, amoebas, and bacteria. And hardly anyone considers himself or herself as an ecosystem. Yet, for a vast number of microscopic organisms, the human body provides everything for a decent life. Each of us is a huge and complex ecosystem—simultaneously a supermarket, playground, and honeymoon suite.

The tremendous complexity of the ecosystem we harbor arises from the sheer number of bacteria (and other critters such as yeasts and amoebas) nesting in our bodies. Bacteria carried by humans greatly outnumber our body cells, probably by a factor of 100 or more. They prosper in well-suited ecological niches of the body and sponge on nutrients produced by the host bodies—you and me.

The relationship between bacteria and their human hosts begins at birth. In the womb, the developing fetus is sterile because it lives in a germ-free environment. As soon as the baby squeezes through the birth canal, however, the first microbes jump on board. The colonization of the newborn has started. In the world outside the womb, germs are everywhere—on the mother's nipples, on the father's hands, in the air. We have no chance of evading them unless we want to spend our entire lives in germ-free enclosures eating only sterilized food—not a very appealing option.

In many respects, the human ecosystem is similar to a bigger "classical" ecosystem. The enormous complexity of both is like a warranty

for being stable, or healthy, even when attacked by intruders. A classical ecosystem—for example, a secluded pond—can deal with occasional disturbances such as droughts or waste disposal, but it surrenders when the drought lasts too long or the pollution load gets too big. Similarly, the human ecosystem is stable enough to withstand most foreign attacks. But when the attack gets too massive (as may happen, for example, with chemotherapy drugs), the ecosystem loses its balance, and infectious germs entering the body can cause severe damage.

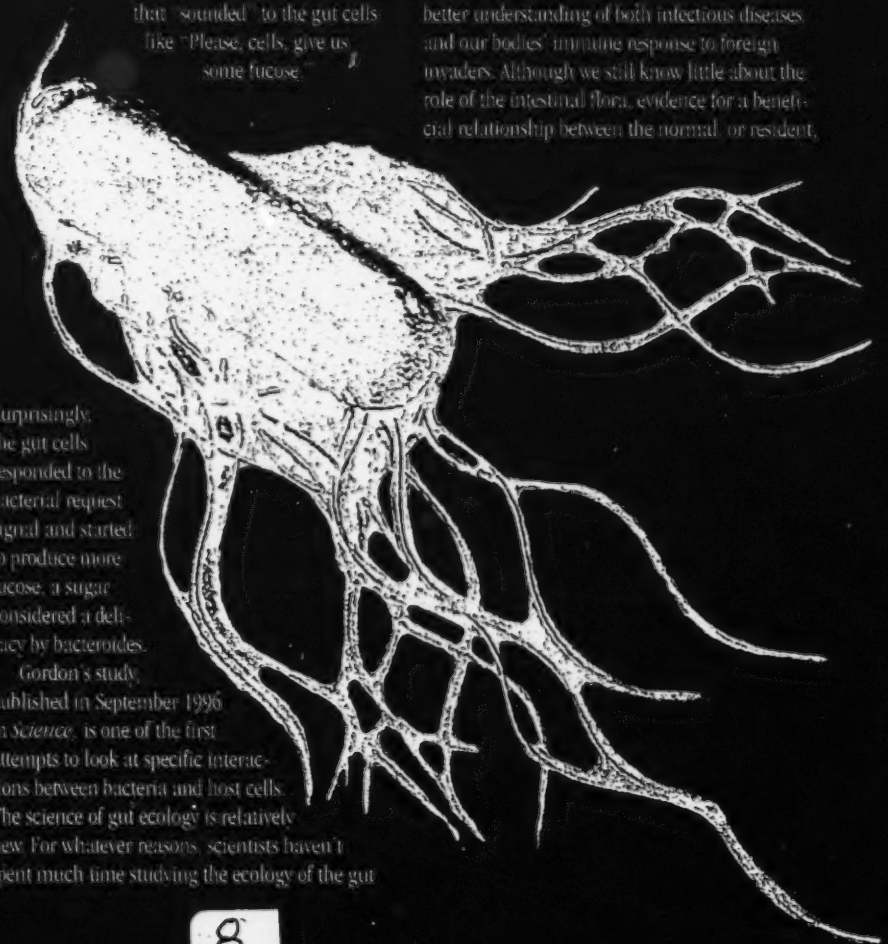
INTESTINAL FLORA

Since the human ecosystem is so complex, some researchers compare it to a tropical rain forest or to a coral reef. Others see the human body as a variety of different ecosystems. For example, our mouths act as a playground for the bacteria that cause tooth decay. In our sweaty armpits, a varied assortment of microorganisms cruise around, creating the odors we try to banish with deodorants. On our skin, acne-causing bacteria prevail. The vulva is a thriving ecosystem in women, as are the mammary glands. But the most prominent of all ecosystems in our bodies is the humid and warm darkness of the gut and the colon, where trillions of bacteria live and die in a mutually profitable relationship with us.

Our regard for our gut inhabitants has not always been as respectful as it is today. At the end of the nineteenth century, when British doctors discovered that our guts were full of bacteria, they were horrified. They believed they were dealing with a terrible new disease, "intestinal blood poisoning," caused by malnutrition. Physicians such as Sir Arthur Lane, the doctor of the royal house, were convinced that only a radical treatment could help eradicate the plague. Lane surgically excised his patients' colons.

Luckily, doctors today don't apply this radical therapy. We now know that gut bacteria are our friends rather than our foes, and that these friendly microbes exist in almost uncountable numbers. One milliliter, or a thousandth of a liter, of gut contains up to a hundred billion (100,000,000,000) bacteria, representing four hundred to five hundred different species. The number of bacteria in one milliliter of our gut is greater than the number of cells in a human brain. The total number of living gut bacteria in a single person, scientifically referred to as the intestinal flora, adds up to a hundred trillion (100,000,000,000,000). For every single body cell, at least a hundred bacteria are in residence, living in harmony with each other and the host cells, or battling against each other for optimal ecological niches in which to survive and thrive. About half of our gut contents, more than two pounds, consist of bacteria.

Researchers are just beginning to understand some of the complex interactions between the zillions of bugs in our intestines and our gut cells. Jeffrey Gordon, a microbiologist at Washington University in St. Louis, Missouri, is one of them. Gordon listened to the biochemical "conversation" between a regular inhabitant of the intestines, *Bacteroides thetaiotaomicron*, and the cells lining the gut. He caught the bacteria sending out chemical signals that "sounded" to the gut cells like "Please, cells, give us some fucose."



Surprisingly, the gut cells responded to the bacterial request signal and started to produce more fucose, a sugar considered a delicacy by bacteroides.

Gordon's study, published in September 1996 in *Science*, is one of the first attempts to look at specific interactions between bacteria and host cells. The science of gut ecology is relatively new. For whatever reasons, scientists haven't spent much time studying the ecology of the gut since the painful discovery, a hundred years ago, that our bowels are infested with bacteria. In the past ten years, however, scientists have realized how important some of our inhabitants may be for our health.

QUESTIONS —AND MORE QUESTIONS

Most questions in gut ecology await an answer. For instance, how can we live together in peace and harmony with so many different bacteria without suffering significantly from their presence? Why do we coexist quietly with some bacterial species while relatively tiny amounts of other species can lead to devastating conditions, such as Legionnaires' disease, brain abscesses, diseases of the immune system, or ulcers? How can our immune systems tell a benign bacterium from a harmful one?

Answering these questions is crucial for a better understanding of both infectious diseases and our bodies' immune response to foreign invaders. Although we still know little about the role of the intestinal flora, evidence for a beneficial relationship between the normal, or resident,

flora and the host body is increasing. For example, *Bifidobacteria*, one of the most abundant groups of bacteria in the gut, seem clearly beneficial to us. Their presence stimulates our immune system and the synthesis of vitamins and proteins. These bacteria also help digestion by breaking down compounds such as starch. The gut flora of breast-fed infants consists of up to 95 percent *Bifidobacteria*, whereas bottle-fed infants show lower levels, similar to those found in adults.

Such facts are interesting not only to scientists but to the food industry as well. Some yogurt manufacturers already heavily promote their "probiotic" products, which contain live *Bifidobacteria*, or *Lactobacilli*, another class of potentially health-promoting bugs. However, some scientists are skeptical about these claims. "Probiotics may help reconstitute a damaged gut flora," says Michael Teuber, a nutrition scientist at the Federal Polytechnical Institute in Zurich, Switzerland, "but for healthy people, probiotic yogurts do not provide more benefits than normal yogurts."

HELPFUL AND HARMFUL BACTERIA

Clearly, not all microbes found in our bodies are beneficial. Disease-causing germs also take their place among the resident flora, although in relatively small numbers in healthy people. And in some cases, harmless bacteria can become harmful. For example, the bacterium *Clostridium perfringens*, a fairly regular inhabitant of the human intestine, normally causes no damage. However, *Clostridium* can turn wild (researchers don't know exactly why and how), making us suffer from food poisoning or from an inflammation of the intestine called enteritis.

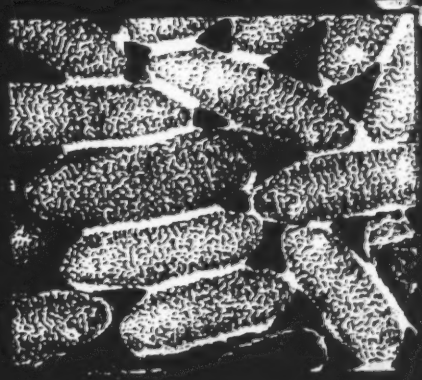
At the thin borderline between good and evil, the resident flora—fortunately for us—normally provide more benefits than drawbacks for our bodies. In the case of the intestinal flora, some researchers have long believed that their mere presence is essential to life. Experiments with rodents have proven the contrary, however—at least for rats. Rats without bacterial flora (reared in a sterile laboratory environment) did survive, although they developed, among other symptoms, a weaker immune system than their peers raised in a normal, germ-bearing, environment. Nevertheless, for herbivores, or plant eaters, such as cattle, sheep, or goats, the resident intestinal flora are necessary for survival. Herbivores need their intestinal flora to convert otherwise indigestible plant products such as cellulose, starch, and some proteins into smaller digestible products. But for meat-eating animals, including humans, the intestinal flora may be helpful but nonessential.

If we look at the entire ecosystem "human body," one beneficial function of our microbial inhabitants clearly stands out: Long before the immune system goes into action, the resident flora act as our first weapon to hinder unwelcome intruders, such as pathogenic bacteria, from successfully lodging in the body. Normally, the resident flora, being much better adapted than pathogens are to the ecological niches prevalent in the body, easily win the fight for survival over the intruders. The dangerous germs

are not allowed to grow, relieving the immune system of its burden of warfare. Furthermore, the resident flora strongly promote the complexity of the immune system by challenging it early in life with a broad range of foreign particles, or antigens. The more antigens a developing immune system confronts, the broader variety of antibodies it produces, and the better it protects us from infectious diseases.

Like other healthy environments, the ecosystem of a healthy person is remarkably stable. Whenever the balance is disturbed—for example, by antibiotics destroying certain resident germs but not others—the composition often returns rapidly to normal after the antibiotic is removed. (In some cases, though, antibiotics dramatically modify the gut flora, allowing resistant, disease-causing germs such as *salmonella* to enter the body.) The ecosystem is thrown out of balance, however, in a person whose body is weakened either by diseases such as diabetes, leukemia, or AIDS, or by cell-killing or immune system–suppressing drugs. As a direct consequence of this unbalanced ecosystem, the barrier built by the resident flora against extraneous intruders weakens, and the door for opportunistic infections eventually opens.

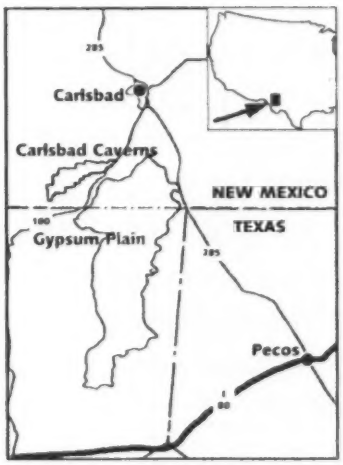
In a way, our body is a mirror of what's going on in the bigger, classical ecosystems. We know that an undisturbed, healthy ecosystem is, like a healthy person, relatively stable. But we also know that natural disturbances such as fire or floods, along with air pollution and other damage caused by people, can destroy the same ecosystem. Acid rain is perhaps not so different from chemotherapy: both are serious attacks on their respective ecosystems. Although the parallels might not be obvious at first glance, they can help to promote seeing our bodies as real ecosystems. And they might help us to remember that every large classical ecosystem consists of many smaller ones, one of them being ourselves. ■



Salmonellae, the cause of several intestinal infections including typhoid fever.

The Hills That

by Robert Evans



The Exploration

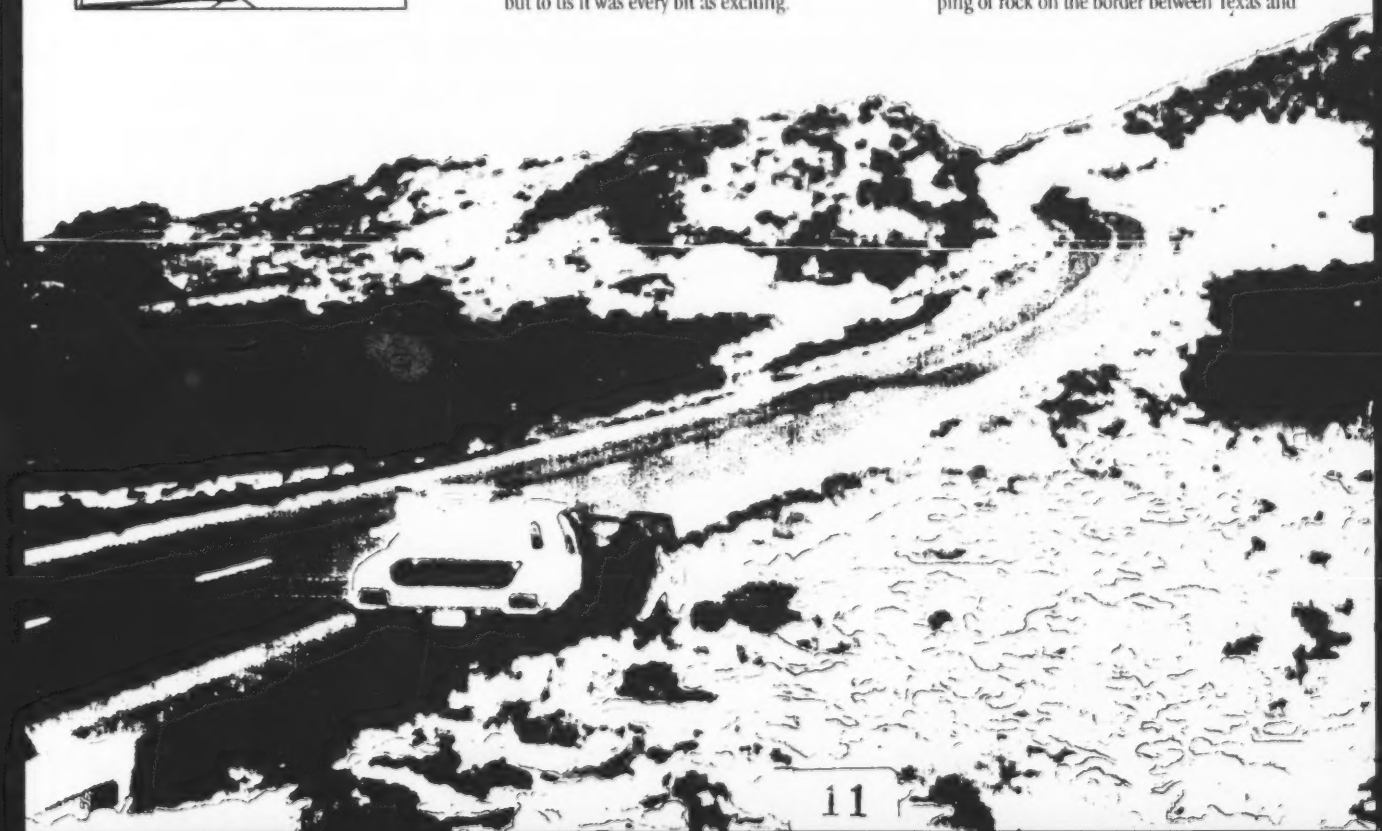
In the sixteenth and early seventeenth centuries, Spanish explorers searched the New World for riches and personal glory. From Mexico, they crossed the Rio Grande, then travelled north across Texas into New Mexico and Arizona. Almost four hundred years later, my friend Doug Kirkland and I travelled to that same area of west Texas and New Mexico on another search—a search for geological knowledge. The company we worked for thought we should explore for sulfur, an important raw material used, for example, in the manufacture of sulfuric acid. We wanted to find out how sulfur deposits formed, because that information would guide future explorations. Our journey was not as dangerous as the first ones across this terrain, but to us it was every bit as exciting.

The Search for Clues

Geologists name the rock units they study so that everybody will have a common vocabulary for the various "beds" and "formations." The one we were interested in, because deposits of sulfur had previously been found within it, is called the Castile Formation. Famous for its beautiful banding, it forms the Gypsum Plain on the west side of the Pecos River—fifty miles long and almost twenty miles wide. It is scrubland, parched and desolate, its surface dusty and occasionally treacherous. The rock underfoot is so soluble that rainwater can easily dissolve holes in it big enough to swallow an unwary traveler.

Doug Kirkland had studied the Castile Formation for a long time. When he invited me to go with him to look at some of the outcrops, I agreed enthusiastically. Although I had seen samples of this beautiful rock, I had never seen it in the wild, so to speak.

On the first morning, we went to an outcropping of rock on the border between Texas and



Bacteria Built

New Mexico. Among the most famous geological sites in North America, it's known simply as "State Line Outcrop." For hundreds of feet alongside a road cut through the Castile Formation, the beautiful banding is on display. I had never seen anything like it, nor have I since. Like every geologist before us, we tried to get samples of the folds, but the gypsum is so soft that the metal of our hammers embedded itself with hardly a sound.

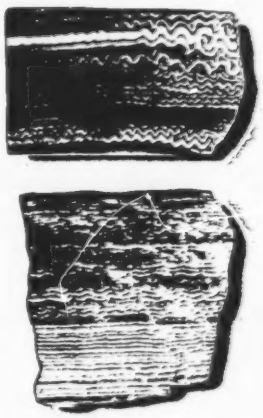
From the state line, we drove south and east to several small hills grouped around a bend in the road. When we walked to the top of one of them, we found that although the rock forming these hills looked identical to what we had just seen, when we struck it with a hammer, it rang with a loud metallic sound. This rock was not gypsum, which is primarily calcium sulfate, but something much harder. It had been changed into calcium carbonate—solid, hard, limestone.

We looked around for clues to this transformation, and found something curious. Digging around in the gypsum soil near the hills, we found flecks of a glossy yellow mineral—native, or pure, sulfur. The sulfate molecule in gypsum consists of sulfur bound up with four oxygen atoms, but we found the native element itself only in the dirt near the limestone hills.

We knew that the change from gypsum to limestone had probably taken place before the rocks we were walking on had appeared at the surface. Starting with material that was mostly calcium, sulfur, and oxygen, nature had produced a rock that was calcium, carbon, and oxygen. Carbon had been added and sulfur had been taken away, although a few traces of the sulfur had been left in the soil.

The key was to understand how carbon had been added. The hills we were looking at were made up of millions of tons of rock, so huge quantities of carbon had to have been brought in to cause the alterations we had seen. What mobile substances contain large amounts of carbon? Petroleum, crude oil, natural gas.

Samples of the Castile Formation. The rock on the top consists of regular alternations of two minerals: thin, dark layers of calcium carbonate (in the form of the mineral calcite), and thicker, light-colored layers of gypsum (hydrous, or water-containing, calcium sulfate). The rock on the bottom comes from one of the hills on the Gypsum Plain. It consists entirely of calcium carbonate, but it has the same features as the gypsum: small undulations, or folds, as though the layers have been squeezed into miniature waves.

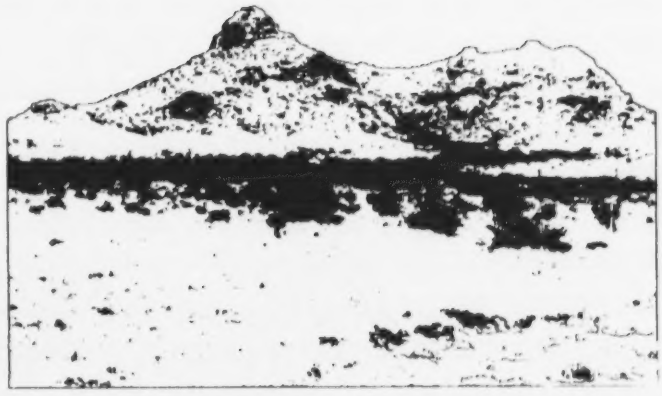


From Gypsum to Limestone

- Water dissolves gypsum—calcium sulfate ($CaSO_4 \cdot 2H_2O$)—to release calcium (Ca) and sulfate (SO_4)
- Bacteria break down organic matter—petroleum or natural gas—into carbon (C) and hydrogen (H)
- Bacteria remove oxygen (O) from the sulfate (SO_4), leaving sulfide ($S^=$)
- Other bacteria oxidize some of the sulfide into native sulfur (S)
- The balance of the sulfide combines with the hydrogen to form hydrogen sulfide (H_2S)
- Carbon dioxide (CO_2) forms, dissolves in the water, and joins with hydrogen to form bicarbonate (HCO_3)
- Calcium (Ca) from the dissolved gypsum reacts with bicarbonate to form calcium carbonate ($CaCO_3$)—limestone

The Process Revealed

Geologists have known since early in this century that some rocks may have been formed by bacteria. Manganese nodules on the seafloor, nodules of pyrite (fool's gold), and others are believed to have formed this way. And since the fifties, there's been a suspicion that sulfur deposits have also been made by the action of bacteria. Doug thought it possible that the sulfur deposits in west Texas and New Mexico had a bacterial origin.



The Castile hills (shown here and on the previous page) are made of limestone. Limestone is less soluble than the surrounding gypsum, so the hills stand up above the surface.

We knew that certain bacteria obtain energy by using sulfate and various forms of organic matter rich in carbon and hydrogen, including petroleum and natural gas. The bacteria are able to break down organic matter by removing hydrogen—a process called *oxidation*—and to break down the sulfate by removing the four oxygen atoms—a process known as *reduction*.

The sulfate (which is a charged molecule, or ion) has a negative charge; the sulfate becomes sulfide, which is also negatively charged and has one sulfur atom. Nature doesn't like having negatively charged sulfur atoms about the place, and where there's a supply of hydrogen, the sulfide gets fixed as hydrogen sulfide, a poisonous gas that smells like rotten eggs. The other by-product of this oxidation-reduction process is the gas carbon dioxide, which dissolves in water and forms negatively charged bicarbonate ions consisting of one hydrogen atom, one carbon atom, and three oxygen atoms.

Doug thought that the Castile Formation might have all the factors needed to allow this chemical and bacterial process to go on. If water dissolved the gypsum, there would be sulfate ions aplenty. If petroleum or natural gas were moving through the rocks, then there would be a supply of carbon and hydrogen. Calcium from the dissolution of the gypsum would be available, bicarbonate ions like to combine with calcium, and the result of their reaction is calcium carbonate, the primary material of the limestone mounds on the Gypsum Plain. All that nature needed for the alteration of these rocks to go on was a colony of sulfate-reducing bacteria. If we could prove that bacteria had been at work, and if we could prove that they had used petroleum, then we might be able to develop a method for exploring for sulfur deposits. And we could announce to the world an exciting scientific discovery: that these huge hills in Texas and New Mexico had been formed by tiny microbes.

Most limestones are formed from the remains of millions of marine organisms such as corals, mollusks, and algae that make shells of calcium carbonate they have extracted from seawater. The carbon they use helps us to distinguish marine limestones from other limestones, because not all atoms of carbon (or of other elements) are the same. They might look the same—if we could see them—and they behave the same, but they don't have the same mass because the nuclei of the atoms vary. In the case of carbon, sometimes the nucleus has six protons and six neutrons (carbon 12), but sometimes the nucleus has six protons and seven neutrons (carbon 13), or eight neutrons (carbon 14), making the atom a little heavier than normal. These three forms of the carbon atom are called *carbon isotopes*. The marine organisms that make calcium carbonate shells use all the isotopes of carbon.

Other marine organisms, small photosynthetic creatures that live in the light-filled upper waters, primarily use the lightest carbon isotope, carbon 12. Their tissues show a higher-than-normal ratio of carbon 12 to carbon 13 or carbon 14. These higher-than-normal values also show up in substances that are derived from their tissues, substances such as petroleum and natural gas, and they would show up in any by-products if the petroleum were consumed. Consumed by bacteria, for example.

The Proof

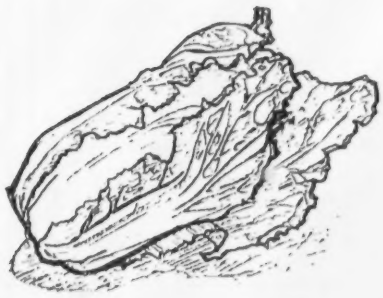
Doug and I needed to find out if the carbon in the calcium carbonate of our limestone hills was "normal" or lighter than normal. In our days in west Texas, we sampled every one of the Castiles we looked at. Then we brought the limestone samples back to the Dallas laboratory where we worked for analysis.

After a few weeks, we had the results. The limestone did have lighter-than-normal carbon, similar to the carbon in the photosynthetic organisms and in petroleum. Bacteria had been at work, consuming petroleum or natural gas, changing the sulfate to sulfide, and causing the formation of masses of calcium carbonate.

A short time later, the bottom fell out of the sulfur market, so our company did no exploring. Doug and I returned to the area, however, to try to estimate how much petroleum or natural gas had moved through the rocks beneath the Gypsum Plain. Whenever you solve one scientific problem, you find half a dozen more to work on. Doug and I were motivated by curiosity, just as the Spanish explorers had been almost four hundred years before. ■

by Karen E. Kalumuck

Flavorful Fermentation: Kimchee



Long before there was refrigeration, fermentation (one form of which is pickling) was used as a primary method of food preservation. In the twelfth century, the armies of Genghis Khan carried fermented foods with them on their European invasions, and pickled cabbage was a staple of the eighteenth century British navy.

Kimchee is a traditional fermented cabbage dish from Korea, popular worldwide for its spicy flavor and high content of vitamins C and B. It's easy to enjoy this multicultural taste of history—you can make it at home with a few simple ingredients.

Ingredients

- A small head of napa (Chinese) cabbage, sliced into 3–5 cm (about 1–2 in.) chunks; divided into five equal piles
- 2-liter plastic bottle, label removed
- Scissors or razor blade
- Six cloves of garlic (more or less to taste) sliced thinly or mashed
- 3 tsp. red pepper flakes or chili powder (more or less to taste)
- 2 tsp. pickling or kosher salt
- Heavy jar (such as a peanut butter jar)

Prepare Your Bottle

Sterilize the bottle and its cap by placing one tablespoon of bleach into the bottle and filling it with warm water. Replace the cap, shake vigorously, and drain, being sure to sterilize the cap and bottle threads. Rinse thoroughly. Wear old clothes in case of splash from the bleach solution.

Use a razor blade or pair of scissors to cut the top off the bottle about one centimeter (about ½ inch) below the shoulder, at a slight angle. Be sure the cap is screwed on tightly.

Layer, Mash, and Ferment

Place one of the piles of cabbage into the bottom of the bottle. Sprinkle onto it about one-fifth of the garlic, salt, and red pepper or chili flakes. Use the heavy jar to mash the cabbage mixture until its volume has decreased by one-half to two-thirds. Notice that water starts accumulating in the bottom of the bottle. Repeat the process with each of the remaining cabbage piles. Your bottle will be about one-third to one-half full of cabbage when done.

To seal the bottle, insert the cut-off top. It's important that all of the cabbage be submerged in the fluid. Over the next several hours, push on the lid to compress the cabbage further. Store the bottle at room temperature.

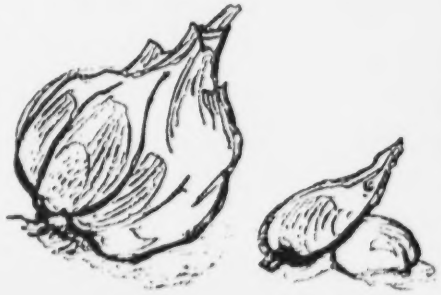
During the next week, press down on the cap once or twice a day, being careful to keep the cabbage below the fluid level. Notice after the second day that as you press down, tiny bubbles float up through the fluid and accumulate along the sides of the bottle. Inhale—does the aroma change from day to day? As fermentation proceeds, you may sense an increasingly pungent, acidic aroma.

Enjoy!

After about one week in a 70°F room (longer in a cool room, shorter in a warmer room), your kimchee should be ready to eat! How much resemblance does your fermented product share with the original ingredients? The cabbage will be limp and wet with a spicy, vinegary taste. Store any uneaten kimchee in the refrigerator.

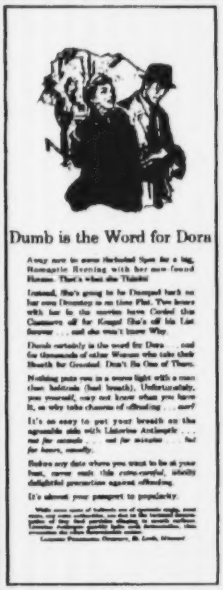
What's Going On?

Bacteria called *Lactobacillus* naturally live on the surface of cabbage and other vegetables, but do not grow rapidly when exposed to air. Adding salt and mashing the cabbage causes water and sugars to flow out of the cabbage cells, making the cabbage limp. Submerging the cabbage in the sugary water creates an ideal anaerobic, or oxygen-free, environment for the rapid growth of *Lactobacillus*. The bacteria use the sugars for their growth and reproduction and produce gas and lactic acid as by-products. The lactic acid gives the kimchee its distinctive vinegary taste. ■



14

CLOROX is FIRST with America's Housewives because it offers BOTH!
1. GENTLER BLEACHING ACTION!
YOU CAN'T FIND A GENTLER BLEACH THAN CLOROX FOR WHITE COTTONS AND LINENS. FOR CLOROX IS ULTRA-REFINED...FREE FROM CAUSTIC AND OTHER HARSH SUBSTANCES... MADE BY AN EXCLUSIVE FORMULA PROTECTED BY U. S. GOVERNMENT PATENT! CHERISH YOUR LINENS WITH CLOROX!
2. GREATER DISINFECTING EFFICIENCY!
BECAUSE CLOROX IS FREE FROM CAUSTIC, IT NOT ONLY BLEACHES MORE GENTLY...IT WORKS FASTER IN KILLING HARMFUL GERMS...DOES A BETTER JOB OF DISINFECTING! GIVE YOUR FAMILY THE EXTRA HEALTH PROTECTION OF A CLOROX-CLEAN HOME!
Hundreds of Public Health Departments endorse the Clorox Type of Disinfection!
USE IN LAUNDRY . . . . . KITCHEN . . . . . BATHROOM
CLOROX



Bathroom – sparkling clean and sanitary with quick-acting Ammoniated MEXOL
Disinfect and Deodorize as you clean –
Do it all with MEXOL

"Bless her heart—it's her duty to put Drāno in all the drains—but I'll do it for her!"
The dangerous sewer germs lurking in every drain never take a holiday. And they breed in muck that liquid disinfectants can't budge. Only Drāno's churning action dissolves the muck—and keeps drains germ-free and free-running.
Put Drāno in every drain—once a week—for about a penny a drain. Makes septic tanks work even better. Get Drāno today at your grocery, drug or hardware store. Also available in Canada.
There's nothing like DRĀNO . . . to keep drains free-running and sanitary

GERM WARFARE ON THE HOME FRONT

BY ELLEN KLAGES

Today, America is the most sanitary country on earth. Our floors are sparkling clean, our breath is fresh, our underarms are dry—even our toilet bowls are cleaner than clean. The aisles of our supermarkets are full of products that sanitize, disinfect, and deodorize. But this wasn't always so. Through the 1850s, Americans lived in squalor. Epidemics of cholera, typhoid, and yellow fever swept through cities with great regularity. Nearly half of all children born died before the age of ten.

Public health officials knew that disease was caused by *miasmas*—noxious gases and fumes that emanated from infected people or from filth and putrefying matter. So at the Quarantine and Sanitary Convention of 1857, they declared war on filth—open cesspools, unclean drinking water, unsanitary housing—and vowed to rid America of disease.

The first challenge came with the Civil War. For every man killed in battle, another six died in field hospitals of gangrene, infection, or epidemics that spread through crowded conditions. Nurses and other women brought their domestic skills to the front, boiling bandages, whitewashing walls, and trying to make hospitals as clean as possible. The mortality rates dropped dramatically.

When the war ended, health reformers moved their efforts from battlefield hospitals to city slums. Thousands of social workers, nurses, and educators—the majority of them women—began the arduous task of educating the unwashed masses about the connection between filth and disease. Dirty, smelly houses and yards were unsanitary and unsafe. School children learned that cleanliness was a virtue, and that clean people were morally superior, saving their families and neighbors from disease. As the message was hammered home, conditions began to improve.

Miasma vs. Germs

European medical publications had been printing articles rejecting miasma-spread disease in favor of Pasteur's germ, or "animalcultist," theory since the 1860s. But the few American medical journals that even mentioned invisible creatures causing disease presented this as a ridiculous notion, and continued to focus on filth and its noxious odors and effluvia.

In 1876, English physician Joseph Lister presented a paper at a medical conference in Philadelphia, outlining his theories about antiseptics and germs. After his lecture, a few American doctors began using carbolic acid as a disinfectant in their clinics and surgeries. As death rates from infection declined, others adopted Lister's methods, although well into the 1890s, the majority of doctors refused to even consider washing their hands between patients. And even though the *method* worked, American doctors continued to reject Lister's basic tenets as unproved and unprovable.

In 1882, the discovery of the tuberculosis bacillus by German researcher Robert Koch was the straw that broke the skeptics' backs. Suddenly, articles in American medical journals introduced doctors to the miraculous "new" discovery. Germ theory rapidly replaced the miasma theory; by the early 1890s, medical textbooks presented bacteriology as an accepted fact.

Curiously, the germ theory had been trickling down to the American public through the popular press since the 1870s. Unhindered by the scientific rigor of the professional journals, magazines were free to print more sensational, imaginative articles. *Popular Science Monthly* began publication in 1872 and carried articles on sanitation, disinfection, and the germ theory, as well as on miasmas. A decade later in 1883, the *Ladies Home Journal* was founded to advise women on home cleanliness, preventing disease, and other domestic matters. Scores of pamphlets and books bombarded readers with more speculation about the "insidious foes" that would stealthily enter their lives and destroy their health.

Very few Americans understood the germ theory, or even noticed the shift from miasma to germs. Rather than replacing one theory with another in their literature, health reformers merely incorporated the two dissimilar theories as elements of the same principle. Dirt, dampness, and darkness, formerly the enemies to be vanquished, were transformed into the allies of germs—the true menace. Disease might be

caused by the odors from a pile of filth, or from invisible creatures living in that filth; it didn't really matter. The message was the same: if you're clean, you won't get sick.

What constituted clean? A mop, soap, and dust rag were no longer enough for the modern woman to kill the *unseen* dirt. Hospital disinfectants and antiseptics began appearing on druggists' shelves. Women's magazines instructed housewives to add formaldehyde, carbolic acid, bleach, and other germ-killers to their pantries to protect their loved ones from the invisible enemy. A good wife and mother made sure her family's home, laundry, food, and bedding were safe from the deadly microbes that lurked in every crevice. By the turn of the century, the American middle class had embraced cleanliness as the greatest defense—and the greatest virtue.

Cleanliness Breeds Content

Cleanliness in the 1920s became something more than a way to prevent epidemics and make cities livable; that goal had been largely achieved. Being clean and fighting germs became a badge of good citizenship, the duty of every good American. The focus of women's magazines and health pamphlets shifted from cleaning up public filth to monitoring personal cleanliness.

If bad smells in bathrooms or sewers indicated the presence of deadly germs, it seemed natural that bad smells coming from the human body must be equally dangerous. Only the odorless person could be truly clean. The Cleanliness Institute, founded by a consortium of soap manufacturers, ran advertisements in every women's magazine warning that to neglect personal cleanliness was to court disaster, not only in one's health, but in one's social standing and chance for success as well.

To fill the demand that they had created, cosmetic and pharmaceutical companies introduced scores of new products—mouthwashes, deodorants, toothpastes, douches—that would kill germs, prevent odors, and save good Americans from ignominy and shame. Personal hygiene evolved from a virtue to a necessity to an obsession. At the forefront of that artificially induced revolution in hygiene was a product called Listerine.

In the mid-1870s, Jordan Lambert had developed a surgical antiseptic and convinced Joseph Lister to lend his name to the germ-killing product. For half a century, Listerine was sold to hospitals, and eventually to the general public, for dressing wounds and for treating throat infections. Sales were steady, but unremarkable.

Don't let your daughter risk **married happiness..** *even her health and womanly charm!*

(Send coupon below for FREE NEW booklet)

Gown by Kenaston

Be sure your daughter knows how important the practice of *complete* hygiene (including intimate *internal* cleanliness) is to married happiness, her health, after her periods and to combat an odor even graver than bad breath or body odor. And be sure she uses ZONITE in her douche because *no other type liquid antiseptic-germicide tested for the douche is so* POWERFUL *yet* SO SAFE *to tissues.*

Developed by a Famous Surgeon and a Scientist

A famous surgeon and scientist developed this ZONITE principle. ZONITE is positively *non-poisonous, non-irritating* yet *so powerfully effective.* It has brought confidence to women by the tens of thousands.

ZONITE'S Miracle-Action

ZONITE removes odor-causing waste substances. It helps guard against infection and kills every germ it touches. It's not always possible to contact all the germs in the tract, but you can BE SURE ZONITE *immediately* kills every reachable germ and keeps them from multiplying. Buy ZONITE today!

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Zonite
FOR NEWER
Feminine Hygiene

NEW! FREE!

*Offer good only in the U.S. and Canada

Mail coupon for FREE book giving full intimate physical facts. Write Zonite Products Corp., Dept. RM-121, 100 Park Ave., New York 17, N.Y.*

Name_____

Address_____

City_____ State_____

Don't let False Modesty and Ignorance ruin Marriage Happiness!

Zonite
FOR NEWER
feminine hygiene

FREE! NEW!

For amazing enlightening new Booklet containing frank discussion of intimate physical facts, recently published — mail this coupon to Zonite Products, Dept. AH-68, 370 Lexington Ave., New York 17, N. Y.

Name_____

Address_____

City_____ State_____

That *Other You* Could End Your Marriage!

Let your husband keep the *real*, the beloved you! Be confident of your intimate feminine hygiene—not troubled with uncertainty . . . another you!

YOU make sure of your feminine daintiness when you douche regularly with "Lysol"!

"Lysol" cleanses the vaginal canal even in the presence of mucous matter. No makeshift like soap, salt or soda can possibly act the same way!

"Lysol" in the famous disinfectant with amazing, greater power to kill germs-life quickly on contact!

Yet, gentle, non-caustic "Lysol" will not harm delicate tissue. Correct douching solution in the simple directions on every bottle. Many doctors advise patients to douche regularly with "Lysol," just to insure daintiness alone, and to use it as often as needed. No greasy aftereffect.

Don't just chance it! Don't ever let neglect create a "dual personality" . . . another you, full of doubts, misgivings and inhibitions! Don't let that other you destroy your love!

Get "Lysol" brand disinfectant today, and use it regularly.

Preferred **3 to 1** *over any other liquid preparation for Feminine Hygiene!*

"Lysol"
A Concentrated Germ-Killer

FREE! EXPERT MODERN ADVICE ON FEMININE HYGIENE!

Harriet Hubbard Ayer, Lehn & Fink Products Corp., Box D.M. 6018, Bloomfield, N. J.

Please send me, in plain envelope, a FREE copy of booklet, prepared in collaboration with a leading gynecologist, entitled, "Don't Depend on Chance."

Name_____

Street_____

City_____ State_____

What secret is your mirror holding back?

NIGHT after night she would peer questioningly into her mirror, vainly seeking the reason.

She was a beautiful girl and talented, too. She had the advantages of education and better clothes than most girls in her set. She possessed that culture and poise that travel brings.

Yet in the one pursuit that stands foremost in the mind of every girl and woman—marriage—she was a failure.

Many men came and went in her life. She was often a bridesmaid but never a bride. And the secret her mirror held back concerned a thing she least suspected—a thing people simply will not tell you to your face.

* * * * * * *

That's the insidious thing about halitosis (unpleasant breath). Your nearest friends rarely know when you have it. And even your closest friends won't tell you.

Sometimes, of course, halitosis comes from some disorganized condition that requires professional advice. But fortunately, and fortunately halitosis is often a local condition that yields to the regular use of Listerine as a mouth wash and gargle.

It is an interesting thing that the safe antiseptic that has been in use for years for surgical dressings possesses these peculiar properties as a breath deodorant. It halts food fermentation in the mouth and leaves the breath sweet, fresh and clean. So the systematic use of Listerine gets you on the safe and polite side. Your friends tell you when your breath is right. Fastidious people everywhere are making it a regular part of their daily routine.

For HALITOSIS use LISTERINE

"Read this little book *carefully*, dear. . . . It explains things so much better than I can"

Lysol Disinfectant

In 1922, Lambert's son, Gerald, wanted to find other uses for the product. His ad agency suggested that they market it as a cure for bad breath. A good idea, except that no one could talk about such things in polite company. Lambert went ahead and asked the company's chemist if Listerine actually did have any effect on bad breath. The report came back: "Listerine is effective in cases of halitosis"— a Latin word meaning "diseased condition of the breath."

Bad breath couldn't be mentioned in polite society, but the "disease" of halitosis could. So Listerine ads headlined "Even Your Best Friend Won't Tell You," and "Always a Bridesmaid, Never a Bride" warned Americans about the hidden enemy that could ruin their lives. Advertising by fear, or "whisper copy," was as effective on sales as Listerine was in the war on germs—Lambert's profits boomed from $100,000 in 1921 to $4 *million* by 1927.

Other products soon copied Listerine's advertising strategy. Anyone leafing through a popular magazine saw dozens of sad tales about women (and an occasional man) who were tragically unaware that germs were causing the odors that prevented them from having the happy lives they dreamed of.

The most frightening of these ads were for feminine hygiene products that women were urged to use to kill those "intimate" germs before they killed a marriage. From the mid-1920s to the late 1950s, two products dominated this fear-driven market. The first, Zonite, claimed to "combat that womanly offense even graver than bad breath" with a diluted solution of the disinfectant sodium hypochlorite—also known as bleach. And the second was "a concentrated germ killer that insures daintiness with antiseptic cleansing," called Lysol.

Lysol was originally developed as a substitute for carbolic acid, and marketed as a household disinfectant. In the mid-1920s, its manufacturer decided to openly (yet subtly) recognize a fact that most women had discovered by word of mouth from friends and relatives—Lysol was an effective, easily available method of birth control. Lysol ads began offering booklets on feminine hygiene and advice on how to avoid "the calendar fear brought on by slight feminine irregularity." Savvy women knew that Lysol's promises to kill germs was code for the fact that it was strong enough to kill *sperm*. For nearly forty years, Lysol was the best-selling woman's hygiene product on the market.

Fortunately, the 1960s saw a rise in consumer awareness and new laws regulating not only a product's labeling, but its use as well. Zonite has disappeared from the shelves; Lysol is back in the household cleaning products aisle of the supermarket. Americans today are more sophisticated consumers, but we're still fighting the germ war as hard as ever.

Last week I bought a package of sponges that boldly proclaims "Kills Germs!" and offers the following warning, reminiscent of the tone of late Victorian health reform pamphlets:

> *Only O-Cel-O™ products with anti-bacterial StayFresh™ technology can kill germs in the sponge—through hundreds of uses!—by preventing the germs from multiplying. Odor and illness-causing germs can grow in ordinary, moist sponges and dishcloths. Don't settle for less.*

Is the average consumer today knowledgeable about bacteriology, microbiology, Lister, or germ theory? Probably not. But after more than a hundred years of education and advertising, it's safe to say we've gotten the message. ■

WHO'S WHO IN GERM THEORY

Anton van Leeuwenhoek (Dutch, 1632–1723). Developed and refined the microscope, circa 1673. Credited with the discovery and first drawings and notes about bacteria.

Louis Pasteur (French, 1822–1895). "Father" of bacteriology and microbiology. Originated the "germ theory" of disease. Developed vaccines for anthrax, cholera, and rabies. Proved that germs are in the air and can be killed, and the spread of disease can be controlled.

Joseph Lister (English, 1827–1912). Revolutionized the practice of surgery. Used carbolic acid to disinfect wounds from germs present in the air. Also introduced antiseptics and disinfectants into hospitals, to stop the spread of germs from one patient to another.

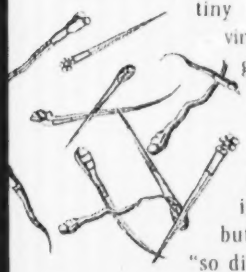
Robert Koch (German, 1843–1910). Discovered the bacillus responsible for tuberculosis, and the cholera bacillus. Won the Nobel Prize for Medicine in 1905.

BEST COPY AVAILABLE

Fragments

by Carolyn Strange

With the microscopes he invented, Dutch cloth merchant and amateur lens grinder Anton van Leeuwenhoek discovered all the major kinds of microbes. Among the "animalcules" he observed were tiny worms in vinegar. Some guests to his house were "keen on seeing the little eels in vinegar," but became "so disgusted at the spectacle that they vowed they'd never use vinegar again," van Leeuwenhoek wrote in 1683. "But what if one should tell such people...that there are more animals living in the scum on the teeth in a man's mouth than there are men in a whole kingdom?"



Green grunge obscuring your fish or fouling your fountain? Drop in a couple of pennies. The tiny bit of copper that dissolves into the water inhibits algae growth.

Don't worry about germs at the Laundromat. The combination of hot water, soaps, detergents, bleaches, and agitation destroy or remove most microbes. Most survivors get zapped in the dryer. But bar soap in public washrooms *should* give you the willies. A study of eighty-four samples of such soap found microorganisms in every one. Over a hundred strains of bacteria and fungi were isolated, including potential pathogens. Some local governments prohibit bar soap in public washrooms. Soap dispensers avoid this problem.

You release about a liter of intestinal gas a day. Bacteria in your colon produce gas when they consume food that you can't digest. Complex sugars are the usual culprits, and they're abundant in high-fiber foods like beans. The trick to avoiding flatulence is to break down those sugars before they get to the bacteria. Beano®, a commercial product purified from mold, contains what human digestive tracks lack—enzymes that digest complex sugars. It's taken with the first few bites of troublesome food.

No two people smell the same to a bloodhound—even identical twins. The difference? Microbes. They transform oils and other skin secretions into various compounds having particular odors. We're constantly shedding skin particles, leaving a flaky trail the dogs track by sniffing. No two people are colonized by exactly the same microbial populations, so our dander trails are unique.

Unlike tube worms elsewhere in the ocean, those living near deep-sea hydrothermal vents have no mouth, gut, or anus. For nourishment and energy, they depend entirely on bacteria housed within their bodies. Nobody knows how the bacteria colonize their host. ▶

Stomach infection by certain yeast strains can cause involuntary drunkenness by fermenting a meal's carbohydrates into alcohol. Blood alcohol levels usually don't reach legal intoxication limits, except with large meals. Until the infection is cured and sobriety returns, victims should exercise caution when driving.

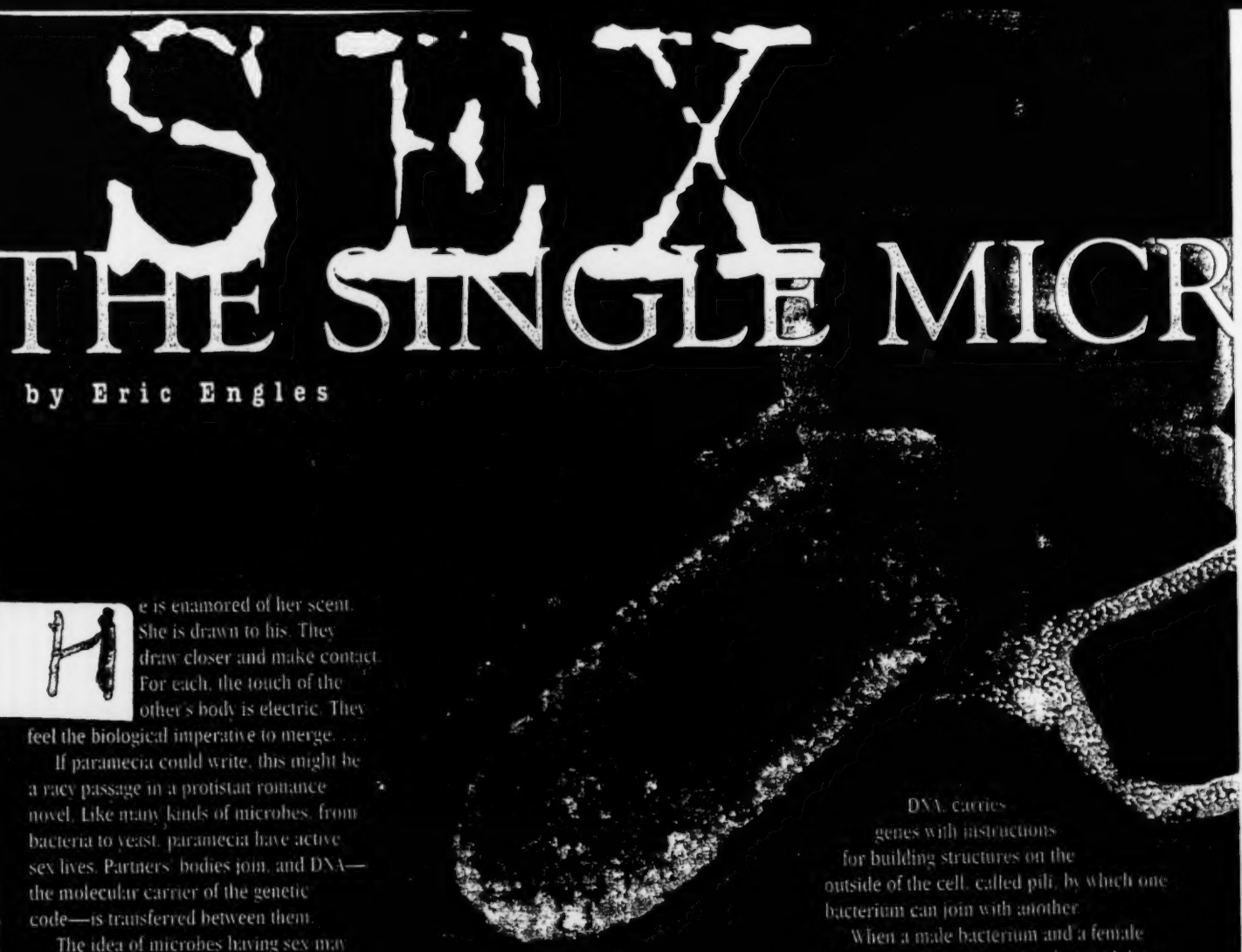
The British weren't always tea drinkers. The rust fungus that destroyed British coffee plantations in the 1860s forced the switch.

Typhoid Mary died of a stroke at seventy, ending twenty-three years of quarantine. Mary Mallon contracted typhoid fever thirty-seven years earlier in 1901, from a visitor to the family that employed her as a cook. She changed jobs frequently over the next six years, as members of each household she cooked for became ill. Along the way, she triggered an outbreak in Ithaca, New York, that killed 1300.

The New York City Health Department tracked her down in 1907, but she refused to cooperate. Police removed her forcibly to a hospital, where a stool test revealed typhoid bacilli, which had colonized her gallbladder. Antibiotics didn't become available until several years after her death, but gallbladder removal could cure typhoid carriers. No believer in germ theory, and afraid she'd die in surgery, she refused. Held against her will and threatened with surgery, Mary became a celebrity. When public outcry gained her freedom in 1910, she promised never to work as a cook again. Five years later, twenty-five cases of typhoid reappeared at a nearby hospital. Eight people died, mostly doctors and nurses, and the hospital cook disappeared. Health officials found Mary—with a new name. Refusing surgery until the end, she remained in quarantine for the rest of her life. ■

SEX IN THE SINGLE MICR

by Eric Engles



He is enamored of her scent. She is drawn to his. They draw closer and make contact. For each, the touch of the other's body is electric. They feel the biological imperative to merge. . . .

If paramecia could write, this might be a racy passage in a protistan romance novel. Like many kinds of microbes, from bacteria to yeast, paramecia have active sex lives. Partners' bodies join, and DNA—the molecular carrier of the genetic code—is transferred between them.

The idea of microbes having sex may seem strange. Based on our elementary or middle school science training, we think of microbes as exemplars of asexual reproduction. Single-celled organisms, we know, reproduce by fission: one cell divides into two, two into four, and so on.

But asexual reproduction is not the same as the absence of sex. Our mammalian prejudice is to think of sex and reproduction as necessarily connected, at least biologically. In one-celled organisms, however, sexual processes (when they occur) are distinct from processes that result in an increase in numbers. Microbial sex is therefore sex reduced to its purest biological form: it is the joining of genetic material from two different parents to form a genetically new individual, and nothing more.

Eons of time and the creativity of evolution have produced astonishing sexual variety in one-celled organisms. As you'll see, our sex lives are very much stereotyped and tame in comparison.

Original Sex

The first organisms on earth to have sex were bacteria, simple organisms whose DNA floats in their cell fluid. No one knows for sure why or how sex evolved, but scientists are fairly confident that bacteria were doing it billions of years ago.

Not all bacterial species engage in sex, but among those that do there are two distinct sexual identities. Bacteriologists call them "donor" and "recipient." Since they parallel human gender, we'll call them male and female. The functional difference between the bacterial "genders" is that males can donate DNA to other individuals and females can't. A relatively small, circular piece of DNA, called the F plasmid, is what makes a male bacterium male. This plasmid, usually separate from the rest of the bacteria's genomic DNA, carries genes with instructions for building structures on the outside of the cell, called pili, by which one bacterium can join with another.

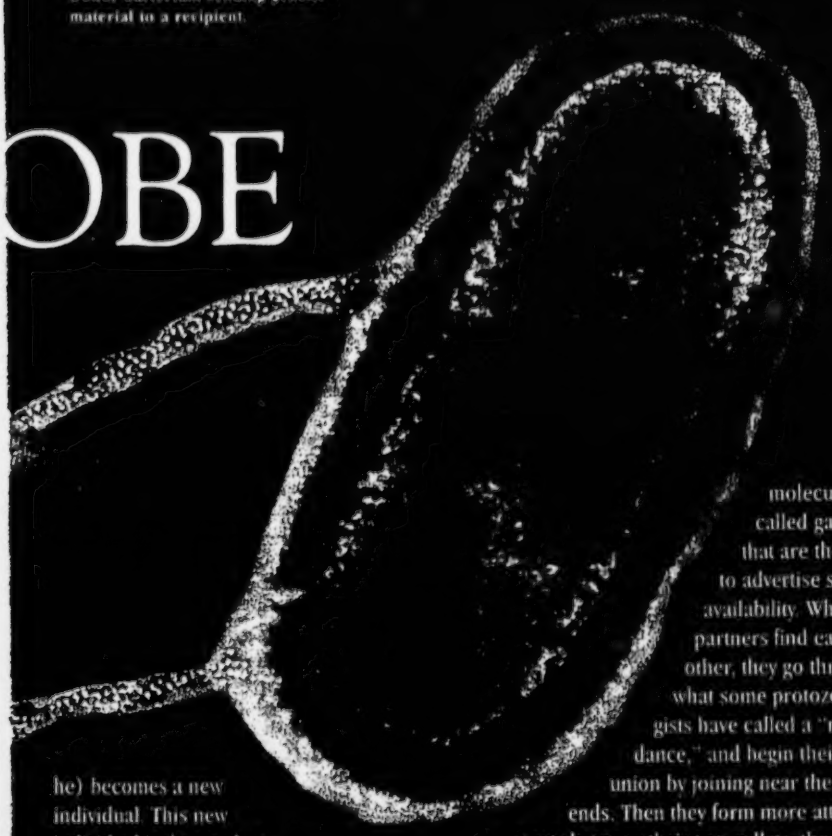
When a male bacterium and a female bacterium encounter each other, and the conditions are right, the male's pilus makes contact with the female, forming a bridge between the two. Then, through a process not completely understood by human voyeurs, the male transfers DNA to the female. Exactly what the male transfers varies. Much of the time it is only a copy of the F plasmid. Sometimes it includes other plasmids (some of which give the owner resistance to antibiotics). And sometimes a substantial part of the male's genomic DNA is transferred, but usually without the F plasmid.

When the female partner receives a copy of the F plasmid, she becomes male. As the owner of this plasmid, "he" can now donate DNA. Conversely, if the male donates the F plasmid without keeping a copy for himself, which sometimes happens, he becomes female after the mating.

Sexual encounters in bacteria change more than just the partners' "gender"—since the female receives new DNA, she (or maybe

BEST COPY AVAILABLE

Donor bacterium sending genetic material to a recipient.



OBE

he) becomes a new individual. This new individual is the product of the recombined genetic material of two parents. One parent—the donor—still exists after the mating, but the other parent is transformed, in a sense, into its own progeny.

Sexy Ciliates

Sex is a very different affair for the protists and one-celled fungi. Though unicellular like bacteria, their DNA is divided into chromosomes and encased in a nucleus. Organisms whose cells have distinct nuclei, including us, are called *eukaryotes*. When eukaryotic microbes have sex, there is usually a mutual exchange of DNA, rather than the unidirectional transfer that happens with mating bacteria.

Among the one-celled eukaryotes that are sexual, the protists called ciliates are best known. Ciliates are named for their cilia, short hairlike organelles on the surface of their bodies. Included in this group are the paramecia, common denizens of ponds.

Before paramecia and other ciliates have sex, or conjugate, potential partners emit molecules called gamones that are thought to advertise sexual availability. When two partners find each other, they go through what some protozoologists have called a "mating dance," and begin their union by joining near their front ends. Then they form more attachments between their two gullets, the areas that function as mouths. These attachments are literal joinings: the cell membranes of each are merged, and their bodies can share contents. At this point, they trade copies of their nuclei and eventually separate.

With their completely symmetrical mating, paramecia are genderless hermaphrodites. They do, however, have different mating types, and there is a strict rule about who can have sex with whom: only individuals of different mating types can mate. Some species have only two mating types—a scheme we humans can identify [redacted]. Other species have evolved beyond a simple binary system. With anywhere from three to eight mating types, they take variety very seriously. Imagine what human society would be like if people were divided into eight different genders!

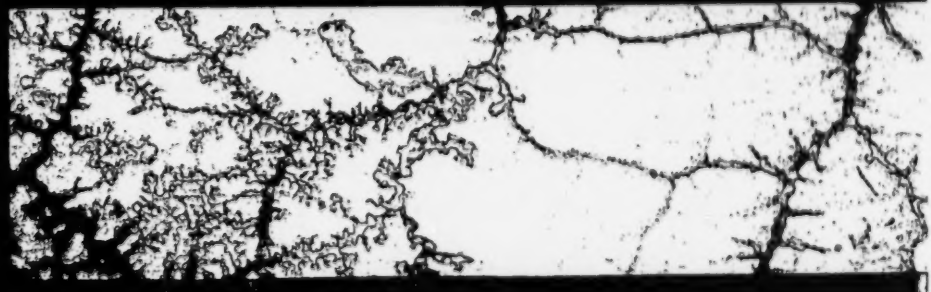
Because of the mutual exchange of genetic material during mating, sex in ciliates is literally transformative. Both partners become new individuals, with different capabilities and traits. There is also evidence that in certain species at least, sex is the key to immortality. Without sex, a population ages and eventually dies out, unable to reproduce. Sex appears to rejuvenate the individuals who engage in it, allowing a population to go on indefinitely.

More Ways of Doing It

Other types of microbes show a variety of fascinating sexual behaviors. Yeasts, for example, can change their mating type if there aren't enough of the opposite type around. In the ciliates called vorticella, mating is a complete merging of the partners, who literally become one. Cellular slime molds make it a group effort: they are normally separate, amoeba-like cells, but when the mood strikes them, hundreds will gather and coalesce into a crawling, multicelled "slug."

Microbes show us that when it comes to sex, almost anything is possible. ■

Physarum polycephalum, also known as slime mold.



Getting Microbes TO DO OUR

by Carol Blaney

When the *Exxon Valdez* spilled petroleum across 1,000 miles of Alaskan shoreline in 1989, one bright spot shone in the dark mess—a patch of white beach. Marine bacteria had scoured black oil from the rocks and sand with some urging from scientists, bringing a ray of hope to an otherwise dismal situation.

The native microbes had the ability to break down hydrocarbons. They got help from gallons of fertilizer, which gave them nitrogen and other naturally limited nutrients to increase their clean-up capacity. The bugs eventually swabbed seventy miles of Alaskan shores.

This vivid demonstration of bacterial gumption gave a boost to the field of *bioremediation*, which depends on microbes to restore environmental health by disposing of wastes. While not a cure-all for environmental ills, bioremediation offers the possibility of dealing with some problems in a natural way.

"This process works. If it didn't, we'd be so inundated with organic wastes, we wouldn't be able to move," says Perry McCarty, a civil engineering professor at Stanford University who studies bioremediation. "Nature recycles everything."

Microbes have gotten a bad name as the cause of diseases, the killers of crops, and the rotters of food. But some, like the Alaskan bacteria, have a marvelous, mostly unappreciated side. For millennia, microorganisms have helped keep the earth in order by cleaning up debris and balancing population sizes.

We humans are learning to use these microbial abilities to do our dirty work. Microbes used for bioremediation now digest explosives, break down cleaning solvents, and mop up other toxic compounds. And in a process known as *biological control*, they wipe out disease-carrying mosquitoes and other pests in a more environmentally friendly way than chemical treatment and other approaches.

A mosquito larva infected with its fungal nemesis, a water mold called *Lagenidium giganticum*.

Urging Microbes into Action

In a quarter-century of using bioremediation, we've learned something about convincing microbes to do our bidding. But they're not operating out of altruism. Like us, they're seeking energy sources to help them survive and reproduce, so a crucial step in bioremediation involves finding out exactly what microbes need.

One need is food. As a group, microbes eat everything. But as individual species, they're much pickier. Some feast on other creatures, injuring or killing them to get nutrients. Others feed more passively, soaking up food from the soil or water around them. Many require oxygen to survive, while others suffer harm in its presence.

These individual quirks, which have helped microbes survive in practically every environment on the planet, are also what make them attractive for dispatching messes. There is often a bacterial gourmand, or a community of them, waiting to swallow the toxic wastes that plague us.

Of course, not all such wastes are dealt with easily. But even some of the difficult ones give way to bacterial voraciousness with a little coaxing. Take explosives in soil, for example. In munitions plants nationwide during and after World War II, Army workers made explosives and regularly washed out the factories, leaving a legacy of contaminated soil. Now, years later, the Army is looking for a way to clean up the mess, and it has turned to microscopic assistants.

At about thirty Army installations, a main contaminant is TNT—short for 2,4,6-trinitrotoluene, its chemical name. TNT may damage the liver, blood, and reproductive organs. This explosive and others could wash into groundwater, which we eventually drink. Cleanup often involves incineration, which is pricey, can cause air pollution, creates sterile soil, and tends to make neighbors nervous.

Normally, soil bacteria won't eat TNT. But John Manning, of the Argonne National Laboratory, found a way to nudge bacteria at the Joliet Army Ammunition Plant into chowing down. In a large tank, he fed bacteria a mixture of molasses and contaminated soil, which prompted them to degrade the TNT without a bang. His next step is to find out whether he can save money and time by dumping the sticky stuff into dirt without first digging it up.

Fungi and bacteria have helped ease other environmental problems. They break down rubber tires for recycling, concentrate metals for disposal, and process other wastes. Even municipal sewage treatment plants use a form of bioremediation. In San Jose, California, for example, naturally occurring microbes break down waste in 133 million gallons of sewage each day.

Bacteria also degrade cleaning solvents that contaminate groundwater. For years, some spot removers, engine degreasers, and dry-cleaning compounds containing chlorine have been dumped on soil and into sewage systems. These carcinogens have spread for miles underground.

The usual way to get rid of such solvents is to draw the water out of the ground to purify it. But Perry McCarty and other researchers around the country have found that naturally occurring

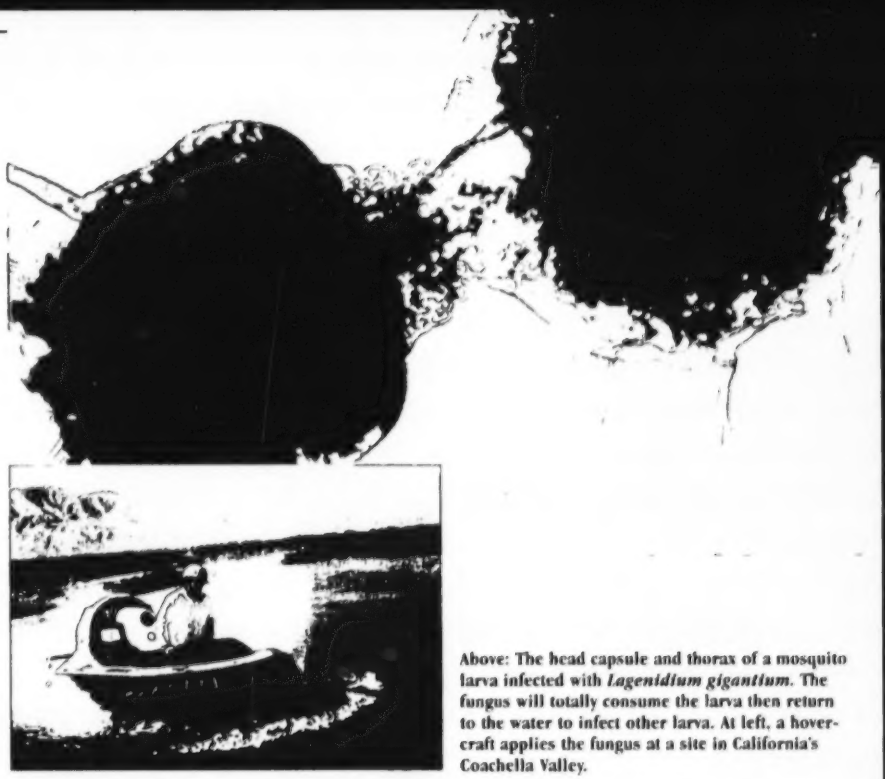
DIRTY WORK

Workers excavate TNT-contaminated soil and add molasses to a bioreactor. A pilot program has shown that feeding molasses to bacteria in TNT-contaminated soil could be a simple and cost-effective alternative for cleanup projects.

bacteria can do just as good a job in the ground, usually at a lower cost and with less environmental disruption.

One problem with bioremediation is that some microbes produce new toxic compounds in the process of degrading the old ones. As they clip off parts of molecules, they leave behind segments that still have the potential to cause cancer or other disorders.

That's not the case with one of McCarty's microbial systems. The chlorine solvents start out toxic, but by the time the bacteria are through with them, they end up as chloride (a form of chlorine), carbon dioxide, and water. Chloride forms salts, so drinking water with too much of it tastes odd. But chloride in small amounts isn't dangerous.



Above: The head capsule and thorax of a mosquito larva infected with *Lagenidium gigantium*. The fungus will totally consume the larva then return to the water to infect other larva. At left, a hovercraft applies the fungus at a site in California's Coachella Valley.

Biological Warriors

Besides cleaning up wastes, microbes can handle another unpleasant task—killing insect pests that plague crops and carry diseases. People have concentrated crops in certain places, and we've accidentally introduced insects to new habitats where they have no native enemies. In doing this, we've made some areas especially attractive to mosquitoes, gypsy moths, and other pests. Through biological control, fungal, bacterial, and viral pathogens can become tiny exterminators of these voracious insects.

At the University of California at Davis, Robert Washino and other researchers have put these ideas into practice with a fungus that wipes out larvae of disease-carrying mosquitoes. The immature insects thrive in standing water, the kind found in wetlands and more than 500,000 acres of California rice fields. As adults, the mosquitoes spread diseases, including two that severely affect the central nervous system.

Mosquitoes' fungal nemesis—a water mold called *Lagenidium gigantium*—grows in water where the larvae live. The fungus stalks its prey by producing microscopic bodies called zoospores. They swim around until they find a larva. Then they attach to and penetrate it, finally filling up the larva's body cavity with fungal cells.

This effective system can kill off mosquitoes in three or four days without any chemical help, Washino says. Besides that boon, the fungus recycles itself, continuing to produce new zoospores as long as weather conditions allow.

Scientists must ensure that a given microbe used for biological control only attacks pests and doesn't wipe out other species. That's different from bioremediation, in which a variety of microbes attack different targets in the course of cleanup. According to Washino, the water mold kills only mosquitoes, and one type of gnat, and it's safe to use. "It's the ideal pesticide," he says.

Despite pathogens' propensity for biological warfare, getting them to attack can challenge the most experienced researcher. Microbes often have specific environmental needs for germinating and infecting their hosts. The mosquito-killing fungus, for example, demands clean, low-salinity water to survive.

Biological control was dreamed up by scientists more than a century ago, but this use of microbes by humans has only been put into practice in the past few decades. The granddaddy of pathogens used to control insects is a bacteria known as Bt, and it may point to one future vision for microbial use.

Bt—*Bacillus thuringiensis*—occurs in soil, on insects, and in many other habitats. It has several subspecies, each of which attacks particular groups of pests, such as caterpillars, beetles, or mosquitoes, and it has been used as a pesticide for more than fifteen years.

Bt strains depend on toxic proteins to kill their hosts. When an insect scarfs up a bit of dirt or a mouthful of a plant, it may also take up bacterial cells and their poisons. Inside the insect's body, the toxins go to work. They latch onto cells in the insect's gut and eventually make them explode, killing the victim. Nasty, but effective.

Even with this arsenal, Bt and its relatives have some weak spots, and scientists are trying to make a better pest-killer. They're using genetic engineering to insert *Bacillus* genes into other organisms, including other bacteria, to overcome the pesticide's problems, such as degrading in sunlight. And researchers are taking another tack, too—combining genes from several Bt types into one, so they hit a variety of insect pests with a single shot.

Remaking microbes may also prove a future direction for bioremediation. Scientists are exploring a variety of ways to improve microbes' capacity to clean up wastes. Still, genetically engineered microorganisms raise public suspicions, and they require regulation to prevent them from causing more environmental damage than they remedy.

In the meantime, unaltered microbes continue to do the jobs they've always done—keeping pest populations manageable. Our task is to act with them, and to reduce their work load when we can. ■

by Fred Stein

BACTERIAL TERRARIUM

With just mud, paper, and an egg, you can grow colonies of multihued microbes!

In the 1880s, a Russian microbiologist named Sergei Winogradsky discovered that watery mud poured into a tall bottle and placed in the sun turned many different colors. He found that by adding a few simple things, such as cheese or paper, he could control which colors appeared. Here's a recipe for making your own Winogradsky column.

Materials

- A clear tennis-ball container or plastic soda bottle with the top cut off
- Container top, or plastic wrap and a rubber band
- Mud from a bay shore or the edge of a shallow pond (the smellier the better)
- Water
- ¼ newspaper page shredded
- 1 raw egg (without shell)
- Bowl
- Spoon
- Lamp with a 40-watt incandescent bulb

To Do and Notice

Remove any rocks or sticks from the mud, and put the mud in the bowl. Mix it with water until it's the consistency of heavy cream.

Remove the label from your container. Put in the shredded paper and egg, add an inch of mud, and mix well. Then, fill the container with mud up to an inch from the top and cover it. Wash your hands after you complete the setup.

Put the container about a foot from a 40-watt bulb that you can leave on all the time. Every few days, briefly remove the container's top to vent off gases. (If too much gas is allowed to build up, it can blow the top off.) If the mud at the top is drying out, add a little water. In a few weeks, you'll see areas of brilliantly colored bacteria. Keep watching, and you'll see the colors develop and change during the next several months.

What's Going On?

Many kinds of bacteria live in mud. Some are decomposers that get nutrients by breaking down organic materials—things like the egg and paper. During the process of decomposition, all the oxygen near the bottom of the container is used up.

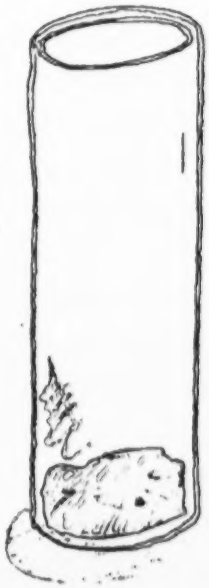
Other bacteria are photosynthetic. Blue-green bacteria near the top of the mud column use light, carbon from carbon dioxide, and hydrogen from water to make carbohydrates and give off oxygen—just like plants. The carbon dioxide they need is released when the decomposers break down the paper and egg.

Red, orange, and green bacteria that grow near the bottom of the column are less tolerant—or completely intolerant—of oxygen. They're photosynthetic, but they get their hydrogen from hydrogen sulfide, the gas that smells like rotten eggs. In your container, hydrogen sulfide is released when the decomposers break down the protein in the egg.

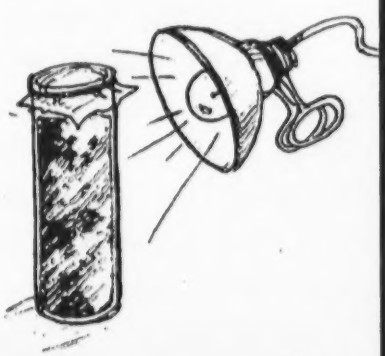
Your mud contained some of each of these kinds of bacteria when you collected it. You provided the bacteria with conditions that are just right for them, and their populations exploded. The colorful patches are colonies of *billions* of bacteria.

So What?

For the first billion years that life existed on the planet, the atmosphere contained little oxygen. Bacteria like those at the bottom of your mud column thrived. It wasn't until about two billion years ago that the blue-green bacteria filled the atmosphere with its photosynthetic waste product—oxygen. This effectively banished other kinds of bacteria to places where there is no oxygen—to mud and sediments and (more recently) to the insides of plants and animals.



But these oxygen-phobic bacteria still have crucial roles to play. Some take part in the global sulfur cycle. Others convert nitrogen into forms needed by plants. And neither cows nor termites would enjoy their cellulose-based diets without the helpful bacteria in their guts that digest the cellulose for them. ■



The Domestic YEAST

by Alice Cascorbi

Yeasts are everywhere—blowing in the wind, resting in the soil. They're found living in the guts of animals, multiplying in puddles, clinging to the bark of trees and the skins of fruits, nestled into fur and feathers. Special yeasts line the walls of termite tunnels. Crush an apple, fresh from the tree, and within hours its juice is fermenting into cider from the wild yeasts on its skin. Notice pink stains on your shower curtain? It's likely *Rhodotorula*, a harmless red yeast that loves moisture.

Wild yeasts, getting into our foods, gave us the first alcoholic drinks, the first leavened breads. A loaf of bread, a jug of wine—and thou? Yes, thou, too—you are home and hearth to millions upon millions of yeast cells. Yeasts live in our mouths, on our skins, and throughout the intestinal tract, but it's rare that they cause us trouble. Ancient cultures took advantage of this with some of the first fermented products. Germanic tribes chewed barley and spat it into a communal bowl. Saliva enzymes turned its starch to sugar, and yeasts—partly from the mouth—fermented the mass into holy ale.

While Laura's and my European ancestors were making ale and learning to raise wheat breads, Tak's in Asia were learning that mashed soybeans, salt, and time led to tasty staples. Soybeans, mashed and salted, ferment into the sauce called miso, which keeps a long time and makes a tasty soup base. *Aspergillus* molds and the yeast *Saccharomyces rouxii* cooperate to make this product. Soy sauce, that quintessence of East Asian cuisine, started as the liquid pooling on the surface of miso. People got a taste for it as a product in its own right, and now

The other night I had dinner at the home of my friends Laura Hill Sakurai and her husband Tak Sakurai. Laura offered the guests wine and beer, while Tak put food on the table: bowls of miso soup, crusty French bread, tempeh stir-fry, soy sauce. Suddenly I realized that the foods being served shared a common source. From the wine and beer to the soy sauce, they were all products of yeast.

It's scarcely possible to have a traditional meal without some yeasted food. But saying "yeast" is a lot like saying "bird." Is it a buzzard or a chicken, an ostrich or a hummingbird? Yeasts are similarly diverse. In 1970, one expert recognized 349 species of yeasts—a group of generally single-celled fungi. Perhaps 200 others have been described since then.

They are a tangle to systematists, who try to separate species based on factors such as how spores form or the amino acid composition of cell walls. Complicating all this is the fact that yeasts, like other fungi, change their appearance radically based on environmental conditions and reproductive state. It's a bit like trying to recognize sugar whether it's melted into syrup or spun into cotton candy.

fermenters aim their mash for one or the other. But both still start with mashed soybeans, salt, water, and yeast.

Northern Europeans mixed honey and water and got mead, their drink of poets. In Greece, Dionysius and his arts thrived instead on crushed, fermented grape juice. Wine has been a major trade article in the Mediterranean since Phoenician times; three thousand years ago, Homer sang of ships upon the "wine-dark" sea.

East Africans grind the grain called *xaafii*, ferment it a few days, and bake it into the stretchy, spongy flatbread called *buddeenaa*. Ladled into a "plate" of round buddeenaa, their spicy stews are eaten wrapped in more buddeenaa—a yeast food that's both staple and utensil.

Indonesian *ketjap*, ancestor of our ketchup, is a fermented soybean sauce. In Mexico, fermented maize balls *(pozol)* have been a staff of life since Mayan days, and traditional beverages *(tesguino)* are fermented from corn stems, cactus, or agave leaves.

Beers have been known at least 4,500 years, and enjoyed from Africa to China. The ancient Sumerians and Egyptians perfected beer from barley. Horse tribes of central Asia made *kumiss*, a mild fermented mare's milk. Given time, warmth, and a little yeast, any liquid with a fair amount of sugar can become an alcoholic beverage.

Yeast History

Beer yeast was first seen in 1680, by microscope inventor Anton van Leeuwenhoek. But not until the mid-nineteenth century did Louis Pasteur prove that the yeast caused the beer to ferment.

Yeasts lead a double lifestyle. They can respire, as we do, using oxygen to break down glucose for energy, and giving off carbon dioxide.

Cellular respiration: glucose + oxygen —> carbon dioxide + water + energy

Or, they can ferment glucose. This process needs no oxygen—Pasteur called it "la vie sans air." It produces less energy than respiration, but lets yeast survive where other microbes would gasp and die. Alcohol is a waste product of this particular fermentation process.

Fermentation: glucose —> carbon dioxide + ethyl alcohol + energy

Pasteur also found that yeasts are so adapted to their "life without air" that they give up respiring when there's lots of sugar around, even if there's plenty of oxygen available! Brewers and bakers both monitor sugar concentrations to keep their yeasts "living right."

Brewing and Baking

Yeasts are humanity's tiniest domestic creatures. While we don't picture yeasts among the cows, corn, and chickens (or the rice, pigs, and soybeans), over the centuries we've selected special strains for making our favorite yeast foods.

Beer brewers use dozens of varieties of yeast, but there are two parent types: Ale yeast, *Saccharomyces cerevisiae*, which sometimes floats on top as it ferments and prefers room temperatures, and lager yeast, *S. carlsbergensis*, which sinks and prefers cooler temperatures.

Beer starts out as a sugary mixture of malted grain called "wort." Brewers pitch in some starter yeast, which respires at first, using oxygen to reproduce madly. The yeast produces carbon dioxide, water, and "beer flavor" compounds—butterscotchy diacetyl and a mix of fragrant esters. Esters vary with the yeast strain; some smell like banana, strawberry, or grapefruit; others disgust drinkers with odors of solvent or cat urine (one reason brewers are picky about their yeast!).

As cell counts rise, oxygen is used up, and the yeast must switch to fermentation. Now sugars are transformed into alcohol. (Wine and sake are made in similar fashion—except, of course, that they start with grapes or rice mash, not wort.)

When the sugar is gone, the yeast has nothing more to eat. It drifts to the bottom of the fermenter and prepares spores to preserve its life in a dormant state. This helps the brewer separate the yeasts from beer, now that their work is done. But beer that looks clear to the naked eye still has 100,000 yeast cells per milliliter before it's filtered.

Most breweries use special strains of yeast, highly purified, and guard their vats against incoming contaminating wild yeast and bacteria. But not the lambic beers, made in a fifteen-square-mile area southwest of Brussels. There, the native wild yeasts and bacteria are invited in! In cobwebby brew halls, age-old wooden casks are filled with sterile wort. As night falls on a warm spring evening, special louvers in the ceiling open, and the wind brings the guests to the table. Feasting on the malted barley and cooked wheat mash, delicately seasoned with special aged hops, the microbes transform the wort into a sour, aromatic, delicate beer that foams like champagne. Do this in Munich or Milwaukee, and your beer is nothing like a Belgian lambic—the unique, prized flavors depend on the blend of wild yeasts and bacteria native to Brussels and nowhere else.

Wild yeasts also gave us the first raised breads. Thousands of years ago, people discovered that ground grain, mixed with water and left in a warm place, bubbled into a spongy mass that baked up lighter and tasted better. The first yeast breads were born. Soon, people saw that a piece of old dough made new dough rise faster and better. Unbaked dough, called leaven, was the first yeast "starter" for bread.

Belgian lambic beer's prized flavor depends on wild yeasts and bacteria native only to Brussels.

When large-scale brewing began in the Middle Ages, European bakers discovered another source of starter: the yeasty scum that rises to the top as beer ferments. But until Pasteur's work, brewers did not know that yeast was vital to their beermaking. It was considered a waste product, good for raising bread, but who knew why? Baker's yeast budded off of brewer's yeast starting in the late eighteenth century, when busy city bakeries needed a more uniform starter to mass-produce bread. Baker's yeast is the ale yeast, *S. cerevisiae*, but baking strains are selected to raise dough fast and not produce a lot of off-flavors. Still, yeast adds flavors that baking powder doesn't. Although the ethanol formed in raising the dough evaporates during baking, it contributes to the formation of flavor esters. Other compounds contained in the yeast cells interact with flour to give the rounded, nutty taste of yeast-raised bread.

Baker's yeast is raised in industrial batches, and fed a slurry of molasses, water, and minerals. Since the point is to produce as many new cells as possible, the process is aerobic, or oxygen-using. Air is stirred or bubbled into the vats to give the yeast ample oxygen, and the level of sugar is carefully kept below the point at which yeast goes anaerobic and ferments. The molasses feed is cut about an hour before the batch is ended, which makes the yeast stop budding and mature into well-fed single cells.

Out of the vat, the baker's yeast is washed and dried, then pressed into cakes or rolled into granules.

Baker's yeast cultures always contain some bacteria. In nature, it's very hard to separate yeasts from other microbes—and sometimes we don't want to. San Francisco sourdough depends on a balanced culture of a yeast and a lactobacillus native to the Bay Area. The yeast raises the bread while the lactobacillus produces lactic and acetic acids (by-products of bacterial fermentation) for the sour flavor. For decades, bakers tried to use the starter to bake real sourdough in other places. When the flavor didn't measure up, people were mystified. The secret seems to be that if you leave the starter too long, yeast overgrows the lactobacillus, drowning out the sour flavors. For the right balance, sourdough must rise no more than six hours—which means that, every six hours, bread must be baked. Outside of the Bay Area, few bakeries want the bother of baking so often, so the "San Francisco sourdough process" remains mostly a special local technique.

Yeasts as Pathogens

Yeasts live on our skin, in our intestines, in all moist cavities of our bodies. Mostly, our bodies don't mind. The immune system usually keeps them in check, but when it doesn't, the results can be agonizing. Seven species of the genus *Candida* are pathogens for humans, and *C. albicans* is the "meanest" of them all. *Candida* infections of the throat, skin folds, or vagina can be painful and annoying, but they're also very common. Almost every woman gets at least one vaginal yeast infection in her reproductive life.

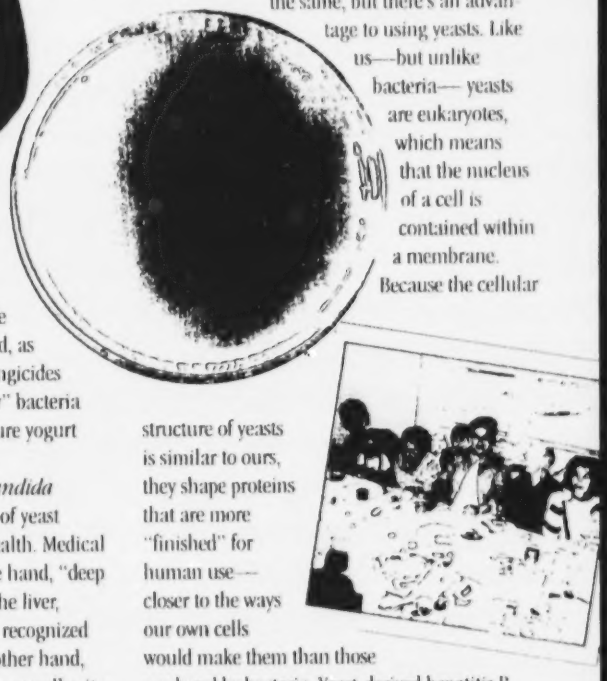
The immune system is most fragile at the beginning and the end of life. Babies' red bottoms and throat thrush in the very old are a manifestation of immune systems not strong enough to fight off yeast. People with AIDS or those taking immunosupressive drugs are also vulnerable.

A normal, strong immune system keeps *Candida* in check with help from "friendly" bacteria in the throat, vagina, and digestive tract. Taking antibiotics may kill off these bacteria, letting *Candida* grow with less competition. *C. albicans* makes enzymes called aspartyl proteinases, which begin digesting proteins in your cell walls. The body's response is inflammation and an onslaught of immune cells to eliminate the invader. In superficial, or surface, infections one may see masses of Candida, like curd, as discharge on red, inflamed skin. Fungicides can cure this; replenishing "friendly" bacteria with acidophilus tablets or live-culture yogurt can help, too.

There's been concern about a *Candida* "syndrome," a systemic overgrowth of yeast leading to fatigue and general ill health. Medical evidence is unclear here. On the one hand, "deep tissue" infection by *Candida*—in the liver, spleen, or blood, for example—is a recognized and very serious condition. On the other hand, patients with the *Candida* syndrome usually cite recurrent superficial infections, not deep-tissue yeast. A 1990 study, published in the *New England Journal of Medicine*, found that specific anti-*Candida* drugs helped such patients no more than placebos did. Still, some follow anti-*Candida* measures, including diets low in sugar with no yeasted foods. Yeast can be an allergen, like anything else, and it's possible that eliminating yeasted foods helps some people feel healthier.

Yeast Biotechnology

Researchers have discovered ways to make yeast take up genes from other organisms, including humans. Such "transformed" yeasts can produce rare human proteins in mass quantities for research or medicine. Bacteria can do the same, but there's an advantage to using yeasts. Like us—but unlike bacteria— yeasts are eukaryotes, which means that the nucleus of a cell is contained within a membrane. Because the cellular structure of yeasts is similar to ours, they shape proteins that are more "finished" for human use—closer to the ways our own cells would make them than those produced by bacteria. Yeast-derived hepatitis B vaccines are already on the market, and other therapeutic proteins are in clinical trials.



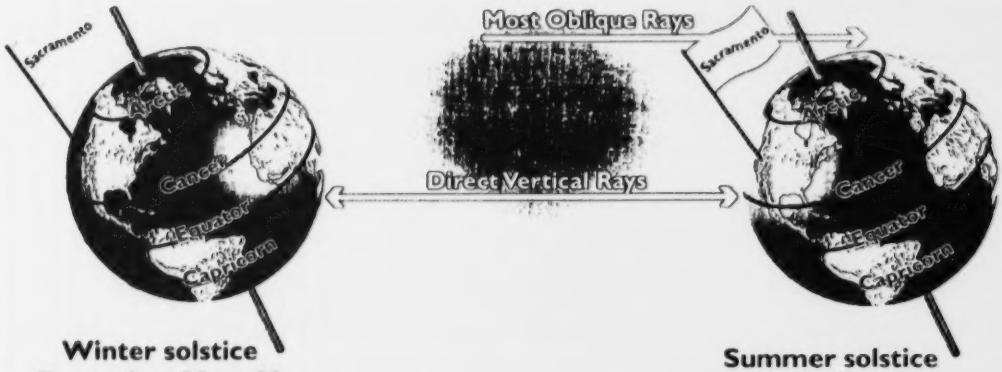
Scientists are mapping the genome of *S. cerevisiae*, and "yeast artificial chromosomes" help scientists isolate the DNA of other species for study.

Our oldest domestic fungus is now a vital tool on the biomedical frontier. ■

Ask Us

by Mary K. Miller

During the summer solstice, the sun reaches its maximum angle of elevation for all latitudes north of the Tropic of Cancer, which is at 23°5′ north (Sacramento is at 38°35′ north). The higher the elevation angle, the more directly, or vertically, the sun's rays strike the earth—delivering the maximum amount of energy to a given area. During the winter, when the sun's rays strike more obliquely, the energy received is less intense because it's spread out over a wider area.



Winter solstice
December 22 or 23

Summer solstice
June 21 or 22

In the part of the country I live in, August is typically the hottest month of the year. June, being the summer solstice month, has the highest number of daylight hours, however. Why is August hotter than June?

—Barry E. Brown
Sacramento, California

You're right: The summer solstice, usually June 21, is the day when the Northern Hemisphere is hit with the most solar radiation. Not only does it experience the greatest number of daylight hours for the year, but this is also the day when the sun is most directly overhead, which makes the sun's energy stronger than at other times. But as you also pointed out, there's a time lag between when the greatest amount of solar radiation per day is received in the Northern Hemisphere and when temperatures are highest.

The time lag is created because of the earth's capacity to absorb and hold on to heat from the sun. The earth's surfaces—water, land, and air—can store this energy before releasing it back into space as terrestrial radiation. As long as more radiation is coming in from the sun than is lost by the earth, temperatures increase. It's like your bank account: if you keep depositing more money into the account than you withdraw, your balance increases. Between June and August, the earth's energy account increases—and temperatures rise—because the deposits of solar radiation are greater than the withdrawals of terrestrial radiation. In the middle latitudes of the Northern Hemisphere, the balance shifts around the end of July to the middle of August. Temperatures begin to fall because the earth begins losing more heat than it receives.

The reverse happens after the winter solstice, which is usually December 21. Even though the daylight hours are increasing, the average temperatures continue to fall until the middle of January or the beginning of February. In those first official weeks of winter, the earth is losing more energy than it's gaining from the sun, making this the coldest time of the year.

Why don't plastic drinking cups and other utensils dry in the dishwasher even if the heat cycle is on? Glass cups and metal utensils dry completely, to the point where they can barely be handled. All the utensils are subjected to the same environment.

—jmw@jmw.mv.com

Two things account for the little puddles of water left on plastic containers after the dishwasher dry cycle. Water molecules are more attracted to each other than they are to plastic. During the rinse cycle, water beads up on plastic instead of spreading into a thin film as it does on metal and glass. With less surface area for the water to evaporate from, drops take longer to dry than thin layers.

The second reason you have to swab the water off your plastic containers is that plastic doesn't conduct heat well. Glass and metal, on the other hand, conduct heat very well. Their higher conductivity means that heat goes through these materials faster, so they conduct heat to the water at a faster rate than plastic does. Because of this efficient heat transfer, any water in contact with glass or metal dries more quickly. Heat conductivity also explains why glass and metal feel hotter than plastic at the end of the dry cycle in your dishwasher. When you try to pick up a glass cup, the heat is conducted to your fingertips at a faster rate than occurs when you touch a plastic cup, even when they're at the same temperature.

Tools and Toys

I was walking home from third grade one fall afternoon. About a block from my house, I found a lunchbox-sized bag of Fritos lying on the sidewalk. Clean, whole, uncrushed, a perfectly fine bag of Fritos. I opened it and munched a few as I was walking up my driveway. My mother met me at the door. "Where did you get those?" she asked. I told her, and to my great surprise, she snatched the bag out of my hand and threw it in the trash. "Don't eat those! You don't know where they've been!" Then I got my first lecture about germs.

My mother told me germs were everywhere. You can't see them, but they're everywhere. Yeah, right. I was skeptical then, but that was because I didn't have a **Build with Beakman Bacteria Farm ($12.95)**. This fascinating kit comes with five plastic petri dishes, a gelatin solution, and some cotton swabs. I put the gelatin in the dishes, then rubbed a swab on parts of my body—the inside of my mouth, the bottom of my foot—and one each in the cat's food bowl and on the kitchen floor. Then I rubbed each swab on the gelatin and put the lid on the petri dish and labeled it "cat bowl" or wherever it was the sample came from. In a couple of days, weird stuff grew on the gelatin—the bacteria from my mouth and my floor! And I could see it!

Mostly the bacteria looked like fuzz or dust or little speckly things—visible, but still pretty tiny. So I took a little bit from each petri dish and put it under the microscope that came in my **5-in-1 Microscope Workshop ($139.00)**. It can magnify up to 1200 times normal size, so I could see all the different shapes and textures and colors of the bacteria. This microscope also has attachments so that I could take pictures of my bacteria with my 110 camera (not included), or project giant pictures of germs onto the wall so that I could share the invisible creatures from my feet with all my friends. Some of them thought it was pretty interesting.

The next day at work, someone left a copy of ***A Field Guide to Germs*** by Wayne Biddle (Anchor Books, paper, **$12.95**) on my desk. This guide to the invisible is a fabulous, informative, and surprisingly amusing book. Pulitzer Prize–winning writer Biddle provides descriptions and drawings and tells of the folklore and history surrounding dozens of common disease-causing microbes—from anthrax to Zika fever. Although many of the diseases some germs cause are horrifying, his introduction says, "This field guide is offered in the spirit of first aid and as a bulwark against phobia. . . . Here, placed in a common context are the top-ranked germs (in prevalence or power or worry factor or even literary interest) from among the billions of potentially unfriendly organisms out there. . . . A little knowledge is better than zip."

A little knowledge is all that was available for a very long time. Although the microscope was invented in the 1600s, no one believed that the little wiggly things were really living creatures, or that they could cause disease. How "germ theory" was developed—and ridiculed, and finally accepted—is the amazing story told in ***The Microbe Hunters*** by Paul De Kruif (Harcourt Brace, paper, **$13.00**). From van Leeuwenhoek to Pasteur, Walter Reed, and Alexander Fleming, every major discovery in microbiology is detailed in this fascinating and very, very readable account of the long war against a legion of invisible enemies.

For younger readers (ages 4-8), I recommend ***Germs! Germs! Germs!*** by Bobbi Katz (Cartwheel Books, paper, **$3.99**). Through rhymes and cartoons, this book from the Hello Science Reader series introduces children to the germs that live inside and outside their bodies. It also explains why food spoils when it's left out of the refrigerator, and why fresh air, sunshine, and washing your hands are important for keeping germs under control.

It doesn't specifically mention that it's not a good idea to eat Fritos that you find on the sidewalk, but I've figured that out by now.

—Betsy McGee

The 5-in-1 Microscope Workshop is available from the Exploratorium Store, where you can shop in person or order by phone at 415-561-0393. Exploratorium Members always get a 15% discount. For membership information, call 415-561-0302. Prices and availability are subject to change.

Related Reading

The Human Body: A Complex Ecosystem
by Nik Walter

"From Birth, the Human Body Houses a Microbe Zoo" by Sandra Blakeslee. *The New York Times,* October 15, 1996, (special section on microbes). A compilation of articles dedicated to microbes, including a profile of the world's leading microbe researcher, Carl Woese.

"The Bugs Within Us" by Ricky Lewis. *FDA Consumer,* Vol. 26, No. 7, September 1992. Descriptions of the human body as a complex of different ecosystems. This article emphasizes pathological aspects, like what happens if the balance of transient and normal flora is disrupted.

Germ Warfare on the Home Front
by Ellen Klages

Advertising the American Dream: Making Way for Modernity, 1920–1940 by Roland Marchand. Berkeley: University of California Press, 1986. Well-written text and dozens of reprinted ads illustrate how advertisers learned to play on our anxieties and change the way we consume.

Chasing Dirt: The American Pursuit of Cleanliness by Suellen Hoy. New York: Oxford University Press, 1995. A fascinating account of American attitudes toward cleanliness and personal hygiene from the pre–Civil War era through the 1950s.

"The Private Side of Public Health: Sanitary Science, Domestic Hygiene and the Germ Theory, 1870–1900," by Nancy Tomes. *The Bulletin of the History of Medicine,* Vol. 64, No. 4, Winter 1990. A scholarly but readable look at how the germ theory influenced public and private behavior and health habits.

Sex and the Single Microbe by Eric Engles

Sex and Death in Protozoa: The History of an Obsession by Graham Bell. New York: Cambridge University Press, 1988. This fairly accessible book chronicles the history of the idea that the apparent immortality of some protistan populations is linked to sexuality.

Sexual Interactions in Eukaryotic Microbes edited by Danton O'Day and Paul A. Horgen. New York: Academic Press, 1981. This collection of articles focuses on the role of chemical substances that cells use to communicate when they are being sexual. There are also some articles on cell-surface interactions during sex.

Getting Microbes to Do Our Dirty Work
by Carol Blaney

"Mauling Mosquitoes Naturally: New Ways to Silence the Buzz" by Tina Adler. *Science News,* Vol. 149, No. 17, April 27, 1996. A clear, concise look at how scientists are controlling disease-carrying insects without pesticides.

Power Unseen: How Microbes Rule the World by Bernard Dixon. New York: W. H. Freeman, 1994. This information-packed account offers 75 vignettes describing species of bacteria, fungi, and other microorganisms that threaten our health, clean up our environment, or shape our future.

The Domestic Yeast by Alice Cascorbi

The Life of Yeasts: Their Nature, Activity, Ecology, and Relation to Mankind by H. J. Phaff, M. W. Miller, and E. M. Mrak. Cambridge: Harvard University Press, 1966. Written for the nonspecialist, this complete and engaging little volume covers yeast biology, ecology, and traditional uses, and is highlighted with occasional anecdotes.

New Complete Joy of Home Brewing by Charlie Papazian. New York: Avon Books, 1991. A readable and fun look at brewing and yeast. Lots of beer lore, and a very clear introduction to basic fermentation processes.

Credits & Acknowledgments

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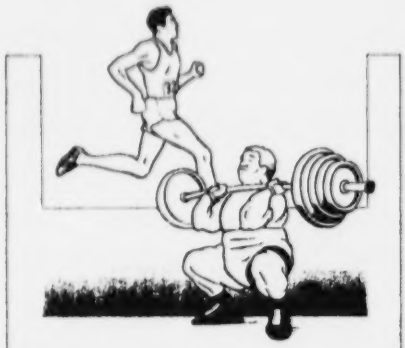

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Join us as we explore fitness. We'll take a historic look at the diets and devices of fitness enthusiasts, find out just how fit a professional hockey player needs to be, and learn about the relationship between our body weight and our genes.

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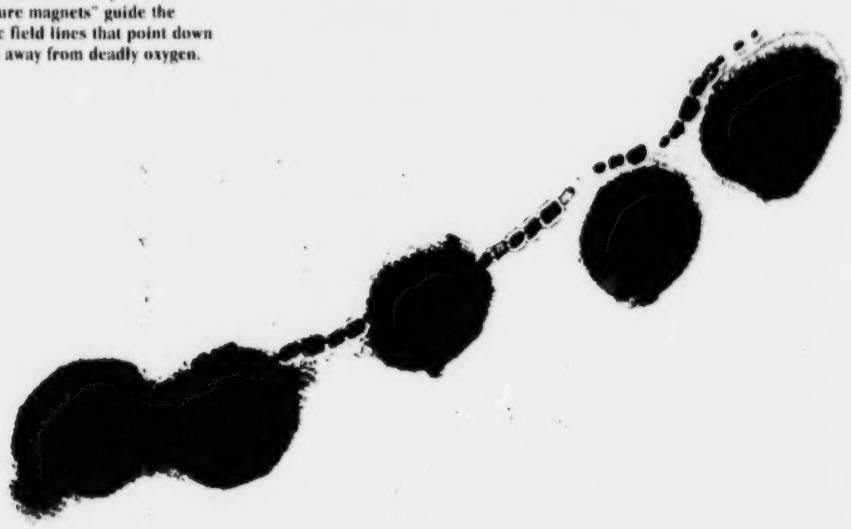

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